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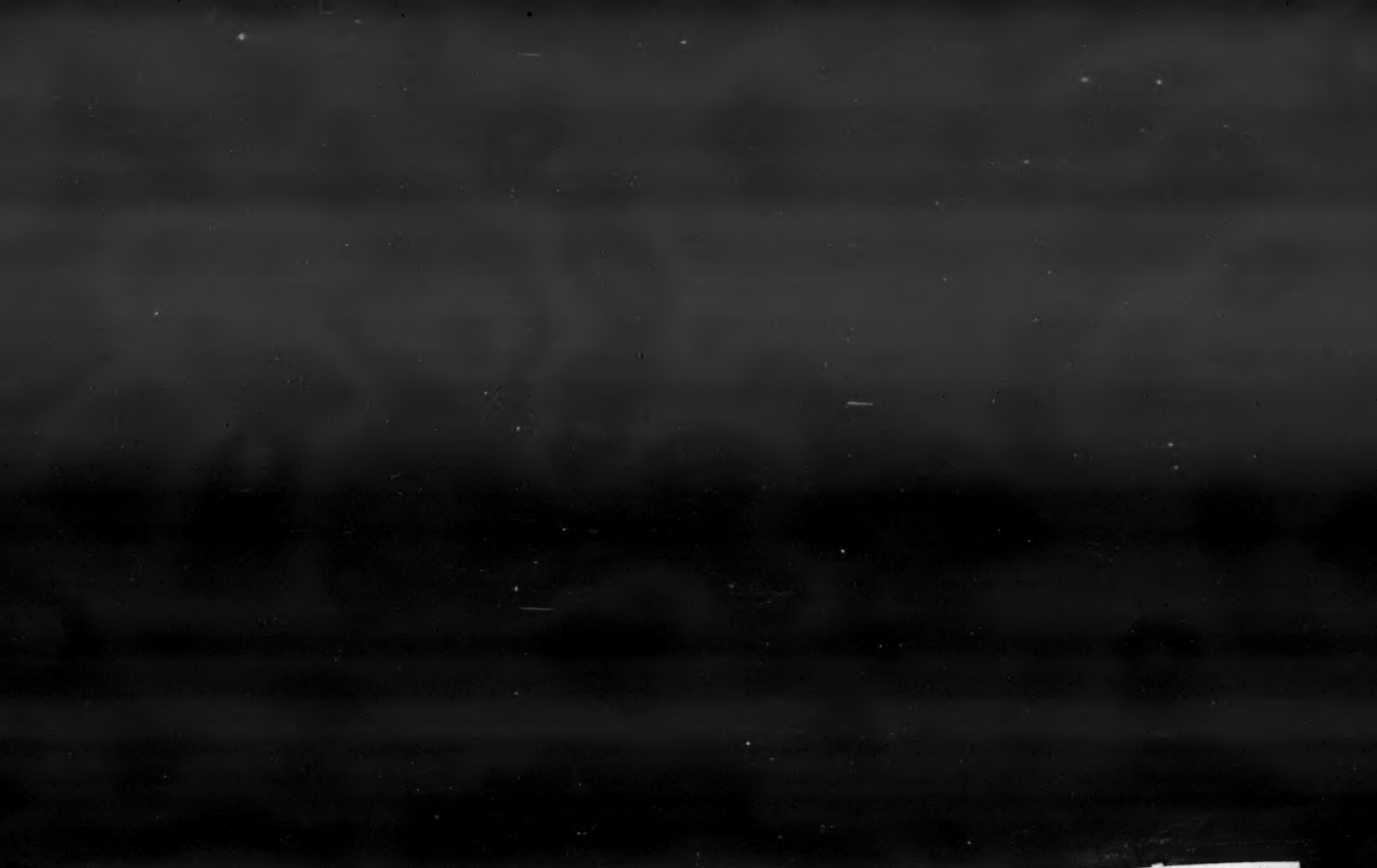

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AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

ART. XXIX.—*Recent Progress in Optics;** by W. LECONTE STEVENS.

Introductory.

THE reviewer who aspires to give an account of recent progress in any department of science is met at the outset by two causes for embarrassment: What beginning shall be selected for developments called recent? What developments shall be selected for discussion from the mass of investigations to which his attention has been called? So rapidly is the army of workers increasing, and so numerous are the journals in which their work is recorded, that the effort to keep up with even half of them is hopeless; or, to borrow a simile employed by the late Professor Huxley, "We are in the case of Tarpeia, who opened the gates of the Roman citadel to the Sabines, and was crushed under the weight of the reward bestowed upon her."

I have selected a single branch of physics, but one which can scarcely be treated rigorously as single. From the physical standpoint optics includes those phenomena which are presented by ether vibrations within such narrow limits of wave length as can affect the sense of sight. But these waves can scarcely be studied except in connection with those of shorter and of longer period. Whatever may be the instruments employed, the last one of the series through which information is carried to the brain is the eye. The physicist may fall into error by faulty use of his mathematics; but faulty use of the senses is a danger at least equally frequent. Physiological

* Address delivered by the Vice-President of Section B at the meeting of the American Association for the Advancement of Science, August 29.

optics has of late become transferred in large measure to the domain of the psychologist; but he in turn has adopted many of the instruments as well as the methods of the physicist. The two cannot afford to part company. If I feel particularly friendly to the psychologist, more so than can be accounted for by devotion to pure physics, it may be fair to plead the influence of old association. If I am known at all in the scientific world, the introduction was accomplished through the medium of physiological optics. But, with the limitations imposed, it is not possible even to do justice to all who have done good work in optics. If prominence is assigned to the work of Americans, it is not necessary to emphasize that this Association is made up of Americans; but, with full recognition of the greater spread of devotion to pure science in Europe, of the extreme utilitarian spirit that causes the value of nearly every piece of work in America to be measured in dollars, we are still able to present work that has challenged the admiration of Europe, that has brought European medals to American hands, that has been done with absolute disregard of monetary standards; work that has been recognized, even more in Europe than in America, as producing definite and important additions to the sum of human knowledge.

In drawing attention to some of this work it will be a pleasant duty to recognize also some that has been done beyond the Atlantic; to remember that science is cosmopolitan. The starting point is necessarily arbitrary, for an investigation may last many years and yet be incomplete. To note recent progress it may be important to recall what is no longer recent.

Light Waves as Standards of Length.

You are, therefore, invited to recall the subject of an address to which we listened in this section at the Cleveland meeting in 1888, when Michelson presented his "Plea for Light Waves." In this he described the interferential comparer, an instrument developed from the refractometer of Jamin and Mascart, and discussed various problems which seemed capable of solution by its use. In conjunction with Morley, he had already used it in an inquiry as to the relative motion of the earth and the luminiferous ether,* and these two physicists together worked out an elaborate series of preliminary experiments† with a view to the standardizing of a metric unit of length in terms of the wave length of sodium light. By use of a Rowland diffraction grating Bell had determined the sodium wave length with an error estimated to be not in excess of one part in two hundred thousand.‡ Could this degree of accuracy be

* This Journal, May, 1886, p. 377.
† Ibid., December, 1887, p. 427.
‡ Ibid., March, 1887, p. 167.

surpassed? If so, it must be not so much by increased care in measurement as by increase of delicacy in the means employed. The principle applied in the use of the interferential comparer is simple enough; the mode of application cannot be clearly indicated without a diagram, but probably all physicists have seen this diagram, for it was first brought out eight years ago.* By interference of beams of light, reflected and transmitted by a plate of plane-parallel optical glass, and then reflected back by two mirrors appropriately placed, fringes are caught in an observing telescope. One of the mirrors is movable in front of a micrometer screw, whose motion causes these fringes to move across the telescopic field. If the light be absolutely homogeneous, the determination consists in the measurement of the distance through which the movable mirror is pushed parallel to itself and the counting of the number of fringes which pass a given point in the field of view. According to the theory of interference, the difference of path between the distances from one face of the plate to the two mirrors should be small; beyond a certain limit interference phenomena vanish, and this limit is smaller in proportion as the light is more complex. In the case of approximately homogeneous light there are periodic variations of distinctness in the fringes. For example, assume sodium light, which in the spectroscope is manifested as a pair of yellow lines near together. In the refractometer there are two sets of interference fringes, one due to each of the two slightly different wave lengths. When the difference of path is very small, or nearly the same for both of these radiation systems, the fringes coincide. The wave length for one is about one-thousandth less than that for the other. If the difference of path is about five hundred waves, the maximum of brightness for one system falls on a minimum of brightness for the other, and the fringes become faint. They become again bright when the difference of path reaches a thousand wave lengths. The case is entirely similar to the familiar production of beats by a pair of slightly mistuned forks.

The method of interference thus furnishes through optical beats a means of detecting radiation differences too minute for resolution by ordinary spectroscopic methods. Spectrum lines are found to be double or multiple when all other means of resolving them fail; and the difficulty of attaining truly homogeneous light is far greater than was a few years ago supposed. By the new method it becomes possible to map out the relative intensities of the components of a multiple line, their distance apart, and even the variations of intensity within what

* Ibid., December, 1887, p. 427.

has for convenience been called a single component. Each of the two sodium lines is itself a double whose components are separated by an interval about one-hundredth of that between the long known main components; and an interval yet less than one-fifth of this has been detected between some of the components of the green line of mercury. Indeed Michelson deems it quite possible to detect a variation of wave length corresponding to as little as one ten-thousandth of the interval between the two main sodium lines.*

This new found complexity of radiation, previously thought to be approximately if not quite simple, proved to be a temporary barrier to the accomplishment of the plan of using a light wave as a standard of length. It necessitated careful study of all those chemical elements which give bright lines that had been supposed to be simple. The red line of cadmium has been found the simplest of all those yet examined. The vapor in a rarefied state is held in a vacuum tube through which the electric spark is passed, and under this condition the difference of path for the interfering beams in the refractometer may be a number of centimeters. A short intermediate standard, furnished with a mirror at each end, is now introduced into the comparer and moved by means of the micrometer screw. Its length is thus measured in terms of the cadmium wave length. A series of intermediate standards of which the second is double the first, the third double the second, etc., are thus compared, and finally in this way the value of the meter is reached.

The feasibility of this ingenious method having been made apparent, Michelson was honored with an invitation from the International Bureau of Weights and Measures to carry out the measurement at the observatory near Paris with the collaboration of the director, M. Benoît. After many months of labor, results of extraordinary accuracy were attained. For the red line of cadmium at an air temperature of 15° C. and pressure of 760^{mm}, two wholly independent determinations were made. From the first a meter was found equal to 1553162·7 wave lengths; from the second, 1553164·3 wave lengths,—giving a mean of 1553163·5, the deviation of each result from the mean being very nearly one part in two millions.† A determination by Benoît from the first series gave 1553163·6, which differs but one-tenth of a wave length from the mean of Michelson's measurements.

The direct comparison of the lengths of two meter bars, though not easy, is a simple operation in comparison with the

* Astronomy and Astrophysics, February, 1894, p. 100.

† Travaux et Mémoires du Bureau internationale des Poids et Mésures, vol. xi, p. 84, 1894.

indirect method just described, but does not surpass it in accuracy. Everyone knows that the meter is not an exact submultiple of the earth's circumference, and that the determination of its exact value from the seconds pendulum is full of difficulty. It may perhaps be said that the optical method is no more absolute than the pendulum method, for no human measurements can be free from error; that there is no possibility of the destruction of the original meter and all certified copies of it; and that there is no proof or probability that molecular changes are gradually producing modifications in standards of length. Even if we should grant that for all practical purposes the labor of determining the meter in terms of an unchanging optical standard has been unnecessary, the achievement is a signal scientific triumph that ranks with the brilliant work of Arago, Fresnel and Regnault. In preparation for it much new truth has been elicited, and light waves have been shown to carry possibilities of application that Fresnel never suspected.

The physicist is nearly powerless without the aid of those who possess the highest order of mechanical skill. The interferential comparer could never have been utilized for such work as Michelson has done with it had not Brashear made its optical parts with such an approach to perfection that no error so great as one-twentieth of a wave length could be found upon the reflecting surfaces.* In the conception, mechanical design, and execution, the entire work has been distinctively American.

The interferential refractometer has been used with much skill by Hallwachs† for comparing the variation of refractive index of dilute solutions with variation of concentration. The fact of solution brings about a change of molecular constitution, affecting both the electric conductivity and the refractive index; and the changes in optical density are measurable in terms of the number of interference fringes which cross the field of view for a given variation of dilution.

Luminescence.

While all work on the visible spectrum is confessedly optical, we can no longer make an arbitrary division point and declare that one part of the spectrum belongs to the domain of optics and the other not. Since the days of Brewster and the elder Becquerel fluorescent solutions have enabled us to bring within the domain of optics many wave lengths that were previously invisible. Stokes's explanation of this as a degradation of

* Travaux et Mémoires du Bureau internationale des Poids et Mésures, vol. xi, p. 5, 1895.

† Wiedemann's Annalen, xlvii, p. 380, and liii, p. 1.

energy, quite analogous to the radiation of heat from a surface on which sunlight is shining, has been generally accepted. But whether the phenomena of fluorescence and phosphorescence are in general physical or chemical has for the most part remained unknown or at least very uncertain. E. Wiedemann, who suggested the term luminescence to include all such phenomena, has within the present year* published in conjunction with Schmidt a part of the outcome of an extended investigation undertaken with a view of clearing up these uncertainties. He has shown that it is often possible to distinguish between cases in which the emission of light springs from physical processes and those in which it is due to chemical action, or at least invariably accompanied by this. We have here, as in photography, a transformation of radiant into chemical energy, to which is superadded the re-transformation of chemical into radiant energy of longer period, and this either at the same time or long after the action of the exciting rays. Indeed between this process and that of photography in colors, the analogy is quite striking. What has generally been called phosphorescence is well known to be the effect of oxidation in the case of phosphorus itself, and in that of decaying wood or other organic matter which under certain conditions shines in the dark. Wiedemann has shown that the shining of Balmain's luminous paint, and generally of the sulphides of the alkaline earths, is accompanied with chemical action. A long period of luminosity after the removal of the source renders highly probable the existence of what he now calls chemi-luminescence. A large number of substances, both inorganic and organic, have been examined both by direct action of light and by the action of kathode rays in a controllable vacuum tube through which sparks from a powerful electrical influence machine were passed. Careful examination with appropriate reagents before and after exposure was sufficient to determine whether any chemical change had been produced. Thus the neutral chlorides of sodium and potassium, after being rendered luminous by action of kathode rays, were thereby reduced to the condition of subchloride so as to give a distinctly alkaline reaction. Many substances, moreover, which manifest no luminescence at ordinary temperatures after exposure, or which do so for only a short time, become distinctly luminescent when warmed. This striking phenomenon is sufficient to warrant the use of a special name, thermo-luminescence Among such substances may be named the well-known sulphides of the alkaline earths, the haloid salts of the alkali metals, a series of salts of the zinc and alkaline earth groups, various compounds with aluminum,

* Wiedemann's Annalen, April, 1895, p. 604.

and various kinds of glass. Some of these after exposure give intense colors when heated, even after the lapse of days or weeks. That the vibratory motion corresponding to the absorption of luminous energy should maintain itself for so long a time as a mere physical process is highly improbable if not unparalleled. That it should become locked up, to be subsequently evoked by warming, certainly indicates the storing of chemical energy, just as the storage battery constitutes a chemical accumulator of electrical energy. Other indications that luminescence is as much a chemical as a physical phenomenon are found in the fact that the sudden solution of certain substances is accompanied by the manifestation of light, if they have been previously subjected to luminous radiation, but not otherwise; that alteration of color is brought about by such exposure; and that friction or crushing may cause momentary shining in such bodies as sugar. There is no conclusive direct evidence thus far that such luminescence as vanishes instantly upon the withdrawal of light is accompanied by chemical action. But Becquerel demonstrated long ago with his phosphoroscope that there is a measurable duration of luminous effect when to the unaided eye the disappearance seems instantaneous.* Wiedemann now shows that when this duration is considerable there is generally chemical change. Since duration is only a relative term, it seems highly probable that even cases of instantaneous luminescence, commonly called fluorescence, are accompanied with chemical action on a very minute scale, and that all luminescence is therefore jointly physical and chemical in character. We have thus color evoked by the direct action of light, which disturbs the atomic equilibrium that existed before exposure, and the manifestation of such color continues only until the cessation of the chemical action thus brought into play.

The influence of very low temperature upon luminescence and photographic action has been studied by Dewar.† The effect of light upon a photographic plate at the temperature of liquid air, $-180°$ C, is reduced to only a fifth of what it is at ordinary temperature; and at $-200°$ the reduction is still greater, while all other kinds of chemical action cease. In like manner, at $-80°$ calcium sulphide ceases to be luminescent; but, if illuminated at this low temperature and then warmed, it gives out light. At the temperature of liquid air many substances manifest luminescence which ordinarily seem almost incapable of it; such are gelatine, ivory, and even pure water. A crystal of ammonium platinocyanide, on the other hand, when immersed in liquid air and illuminated by the electric

* Becquerel, Comptes Rendus, xcvi. 121.
† Chemical News, lxx, p. 252, 1894.

light, shines faintly when this is withdrawn. If now the liquid air be poured off so that the crystal rises rapidly in temperature, it glows brightly.

Luminescence and Photography.

Photography, like luminescence, is a manifestation of the transformation of energy, most frequently of initial short wave length. The production of color by photography is nothing new. It was noticed by Seebeck nearly a century ago that silver chloride becomes tinted by exposure to ordinary light, with accompanying chemical change; that if then subjected a long time to red light it assumes a dull red hue, or a dull bluish hue if held in blue light. It is likewise possible by proper selection of luminescent salts to produce a selected series of tints during and after exposure to those rays which are most effective in photography. But such colors cannot be made fixed and permanent. The problem of securing on the photographic plate a faithful and lasting reproduction of the various tints of a spectrum thrown upon it, has baffled most of those who grappled with this subject. That it has been fully and quite satisfactorily solved cannot yet be affirmed, but the last few years have brought a much nearer approach to success than an equal number of decades previously. Viewed from the scientific standpoint, the goal has certainly been touched, even if commercial demands are still made in vain.

Stationary Light Waves.

Two quite different methods are to be considered in tracing the recent development of this interesting application of optical principles. The first is originally due to Becquerel,* but lately in the hands of Lippman it has been improved and brought much nearer to success than by its originator. It depends upon the production of stationary waves of light. Everyone is familiar with the formation of stationary waves upon an elastic stretched cord, and with the acoustic exhibition of stationary air waves in a closed tube by Kundt's method of light powders. That similar loops and nodes must be produced under proper conditions by interference of waves of light would appear obviously possible; and so long ago as 1868 Dr. Zenker† of Berlin explained the photographic reproduction of color, so far as it had then been accomplished, by reference to stationary light waves. But no definite proof of their production had been brought forward. A few years ago Hertz demonstrated objectively the electro-magnetic waves whose

* Edmond Becquerel, Ann. de Chimie et de Physique, III, xxii, p. 451, 1848.
† Zenker's Lehrbuch der Photochromie, Berlin, 1868.

existence had been foretold by Maxwell's genius; and with suitable apparatus stationary electric waves are now almost as readily made evident as are those of sound. Hertz's brilliant success stimulated his fellow countryman, Otto Wiener, to undertake the apparently hopeless task of producing and studying stationary light waves. Wiener's admirable work* excited great interest on the continent of Europe, but it has been singularly neglected in England and America. It is worth much more than a passing notice.

Assume a plane silvered mirror upon which a bundle of rays of monochromatic light falls normally so as to be reflected back upon its own path. The superposition of reflected and direct waves causes a system of stationary waves, but under ordinary conditions these are wholly imperceptible. The nodes are formed upon a series of planes obviously parallel to the reflecting plane at successive distances of a half wave length. If now we consider a plane oblique to the mirror, it will cut these successive nodal planes in parallel lines whose distance apart will be greater in proportion as the oblique plane approaches parallellism to the mirror. Although a half wave length of violet light is only $\frac{1}{5000}$th of a millimeter, it is easy to conceive of the cutting plane forming so small an angle with the mirror that the distance between the parallel nodal lines shall be a thousand times a half wave length. Such would be the case if the inclination of the cutting plane is reduced to a little less than four minutes of arc. The nodal lines would then be $\frac{1}{5}$th millimeter apart, and readily capable of resolution if their presence can be manifested at all. Imagine a very thin transparent photographic film to be stretched along the oblique cutting plane, and developed after exposure to violet light as nearly monochromatic as possible. Then the developed negative should present a succession of parallel clear and dark lines, corresponding to nodal and anti-nodal bands along the oblique plane, the photographic effect being annihilated along an optical nodal line.

The realization of a photographic film thin enough for such an experiment is quite conceivable when we remember that under the hammer gold is beaten into leaves so delicate that 8000 of them would be required to make a pile one millimeter thick. By electro-chemical deposit Outerbridge† has made films of gold whose thickness is only $\frac{1}{100000}$th of a millimeter, or $\frac{1}{60}$th of a wave length of sodium light. Wiener obtained a perfectly transparent silver chloride film of collodion, whose thickness was about $\frac{1}{30}$th of a wave length of sodium light. This was formed on a plate of glass and inclined at a very

* O. Wiener. Wiedemann's Annalen, xl, p. 203, 1890.

† Journal of the Franklin Institute, vol. ciii, p. 284, 1877.

small angle to a plane silvered mirror which served as reflector. From an electric arc lamp the light was sent through an appropriate slit and prism, so that a selected spectral band of violet fell normally on the prepared plate in the dark room. The developed negative presented the alternate bands, in perfectly regular order more than a half-millimeter apart. Various tests were applied to guard against error in interpretation, and the existence of such stationary waves was proved beyond all doubt.

These waves, moreover, when polarized light was employed, furnished the means of determining the direction of vibration with relation to the plane in which the light is most copiously reflected when incident at the polarizing angle, and thus of subjecting to experiment the question as to whether the plane of vibration is coincident with this plane of polarization or is perpendicular to it. The former of these views was held by Neumann and MacCullagh, the latter by Fresnel. Let a beam of polarized light fall upon the mirror at an angle of about 45°. If the vibrations in the incident beam are parallel to the mirror, and hence perpendicular to the plane of polarization, those of the reflected and incident beams will be parallel to each other and hence capable of interference. But if the vibrations of the incident beam are in a plane identical with that of incidence, and hence in the plane of polarization, the vibrations of incident and reflected beams are in mutually perpendicular planes and hence cannot interfere. Wiener obtained interference fringes when the light was polarized in the plane of incidence, while that polarized in the plane perpendicular to this gave no trace of interference. The theory of Fresnel was thus confirmed experimentally. Again, the familiar phenomena of Newton's rings show us that on changing media there is a change of phase of the incident light, else the central spot where the two surfaces come into optical contact would be white instead of black. But there has been difference of opinion as to whether this change of phase occurs at the upper surface of the air film, where the light passes from glass to less dense air or at the lower surface where it passes from air to more dense glass. In the latter event there should be a node at the reflecting surface. Replacing the silvered plane surface by a lens in contact with the photographic film, Wiener obtained circular fringes with no photographic action at the center, showing the nodal point to be at the point of contact, and thus again confirming the theory of Fresnel.

[To be continued.]

Art. XXX.—*The Quantitative Determination of Perchlorates;* by D. Albert Kreider.

[Contributions from the Kent Chemical Laboratory of Yale College—XLIV.]

The method usually employed for the quantitative determination of perchlorates, by igniting to the chloride and weighing the halogen as the silver salt, is indirect and subject to error, especially as my experience proved, where the free acid is to be determined and where, consequently, an alkali which is apt to contain chloride is used to form the salt for the ignition. To purify the salt for this method only adds to the complication, and therefore a more satisfactory process was sought. In a recent article* from this laboratory by Professor Gooch and myself, a method for the detection of alkaline perchlorates associated with chlorides, chlorates and nitrates was detailed, with mention of certain efforts towards a quantitative determination. As throwing light upon the peculiar properties of perchlorates, and as an introduction to the satisfactory method which I have finally developed, some of the results of these earlier efforts will here be given.

In studying the properties of perchloric acid in the form of its potassium salt, we found that when treated with potassium iodide in the presence of boiling phosphoric acid, no reduction of the perchlorate is effected; unless indeed, the boiling be continued till the temperature rises to 215° to 220° C, where the meta-phosphoric acid begins to form. But when the meta-phosphoric acid (made by heating the syrupy ortho-acid to 360° C) is directly applied in the presence of potassium iodide and kept at a temperature of about 200° C, iodine is copiously evolved. To test this reaction quantitatively a number of experiments were made in an apparatus consisting of a retort, into the tubulature of which a glass tube was carefully ground and prolonged so as to reach to the bottom of the bulb and serve for the passage of a current of carbon dioxide, used to expel the air and carry the iodine into the receiver. The neck of the retort was bent so as to reach to the bottom of an Erlenmeyer receiving vessel, containing a solution of potassium iodide, which was trapped by a side-necked test tube. After introducing the perchlorate with the iodide and meta-phosphoric acid, all air was expelled by carbon dioxide and heat applied. The iodine collected in the receiver was titrated with decinormal thiosulfate, from which the perchlorate was calculated.

Table I gives the results of several experiments performed in this way, which prove that even with a large excess of potas-

* This Journal, vol. xlviii, p. 38.

sium iodide the perchlorate is so slowly reduced that the hydriodic acid escapes before the reduction is completed. In order to delay the distillation of hydriodic acid until the perchlorate had been completely reduced, the potassium iodide of experiment (3) was introduced in a short tube sealed at one end, so that the meta-phosphoric acid could attack it only slowly, and the heat quickly raised to about 300° C, but evidently without advantage. In experiment (4) the iodide was introduced in the same way, but the heat was applied gradually and more moderately, with considerably improved results.

TABLE I.

	$KClO_4$ taken. grms.	$HOPO_2$ used. cm^3	KI used. grms.	$KClO_4$ found. grms.	Error. grms.
(1)	0·1000	15	5·	0·0741	0·0259—
(2)	0·1000	17	10·	0·0844	0·0156—
(3)	0·1000	15	5·	0·0364	0·0636—
(4)	0·1000	15	5·	0·0977	0·0023—

A complete reduction of the perchlorate evidently necessitated the means of introducing the iodide in sufficient quantity and at will.

For this purpose the tube serving for the introduction of carbon dioxide was enlarged so as to hold the iodide, which could then be added to the solution at any time by a manipulation of the rubber conducting-tube for carbon dioxide, which would draw the acid up to the iodide and, retreating, would carry back an easily regulated quantity of the latter.

TABLE II.

	$KClO_4$ taken. grms.	KI used. grms.	$KClO_4$ found. grms.	Error. grms.
(5)	0·1000	5·	0·0984	0·0016—
(6)	0·1000	3·	0·0924	0·0076—
(7)	0·0500	2·	0·0508	0·0008+
(8)	0·0500	2·	0·0479	0·0021—
(9)	0·1000	7·	0·0977	0·0023—
(10)	0·1000	3·	0·0925	0·0075—
(11)	0·1000	3·	0·0999	0·0001—
(12)	0·1000	2·	0·0994	0·0006—
(13)	0·1000	4·	0·0966	0·0034—

Table II gives a number of results obtained in this way. Experiments (10), (11) and (12) differed from the others only in the employment of a bulb pipette instead of the retort: one end being bent so as to reach to the receiver and the other cut off rather short with a tube ground into it, serving the same purpose of conducting carbon dioxide and holding potassium

iodide; the greater inclination of the potassium iodide tube made possible by this change appearing to offer advantages for the more gradual and regular introduction of the iodide. The amount of meta-phosphoric acid used was in all cases 15 cm³. In experiment (13) heat was applied by means of a bath kept at 230°.

While several of these determinations gave only admissible errors, the irregularity of the remainder and the uncertainty in striking just the proper conditions for good results, proved the method worthless at least in that shape.

The experiments of Table III record the results of adding the acid drop by drop to an intimate mixture of the powdered perchlorate and iodide kept hot.

TABLE III.

	$KClO_4$ taken. grms.	KI taken. grms.	$KClO_4$ found. grms.	Error. grms.
(14)	0·1000	4·	0·1036	0·0036+
(15)	0·0500	2·	0·0502	0·0002+
(16)	0·0500	3·	0·0515	0·0015+

The high results of this table doubtless point to the dissociation of hydriodic acid or to the partial reduction of the meta-phosphoric acid in the temperature, which would naturally rise higher where so small an amount of liquid was present. But when the meta-phosphoric acid was there in greater amount the distillation of the hydriodic acid before the complete reduction of the perchlorate could not be prevented.

An ordinary mixture having thus been found insufficient to hold the hydriodic acid to the reduction of perchlorates, a search for some compound in which the perchlorate could be fused with an excess of potassium iodide and the mixture thus obtained subjected to the action of meta-phosphoric acid resulted in the employment of zinc chloride. Anhydrous zinc chloride was found to fuse at about 200° C. The perchlorate and iodide could be added to this fusion and the whole melted, thoroughly diffused and cooled without any evolution of iodine. This mass, when treated with meta-phosphoric acid in the apparatus previously employed, melted gradually with a copious evolution of iodine. Table IV shows the quantitative action. The amount of zinc chloride used was roughly taken about equal to that of the iodide.

TABLE IV.

	$KClO_4$ taken. grms.	KI taken. grms.	$KClO_4$ found. grms.	Error. grms.
(17)	0·0500	5·	0·0552	0·0052+
(18)	0·0000	5·	0·0044	0·0044+
(19)	0·0000	4·	0·0057	0·0057+

In (19) a mixture of cadmium iodide and potassium iodide taken in the proportion of their molecular weights was substituted for the zinc chloride. The known salt corresponding to the formula $CdI_2.2KI+2H_2O$ was not so convenient because of its high melting point —230° C; but when the two iodides are taken in the proportion of their molecular weights, the mixture fuses at about 200° C. Although this mass after fusion was more easily soluble than the zinc residue, the blank determination revealed a source of error equally disparaging.

Gaseous hydriodic acid passed into a mixture of the perchlorate and meta-phosphoric acid at a temperature between 200° and 300° C, was markedly less effective than the generation of the acid on the spot; and the distilling of the perchloric acid by meta-phosphoric acid into a receiver of potassium iodide yielded only a trifling amount of iodine, while the passage of hydriodic acid over the fusing perchlorate in a short combustion tube was precluded by the high melting point of the perchlorate endangering the dissociation of the halogen.

The invariably high results obtained by the use of meta-phosphoric acid in all those experiments in which there was a reasonable assurance that the hydriodic acid was held till the perchlorate was completely broken up—experiments (13), (14), (15), (17), (18) and (19)—indicated either a dissociation of hydriodic acid or a partial reduction of the meta-phosphoric acid. Of the latter cause there were some grounds for suspicion, but as its determination led too far from the object of the investigation, the use of phosphoric acid was abandoned. So far as our experience extended there remained then nothing among the reagents of the wet methods which was sufficiently active and stable enough to warrant its application. Fusion alone seemed capable of extracting the oxygen from the perchlorate. A number of preliminary tests were therefore made on certain salts of the halogens, in the hope of finding one which would be acted upon by the oxygen of the perchlorate with the liberation of the halogen, which latter could be collected in a receiver of potassium iodide and titrated with thiosulfate.

The double chloride of aluminum and sodium, $Al_2Cl_6.{}_2NaCl$, melts at about 200° C, and was in other respects desirable. When fused with potassium perchlorate, chlorine was copiously evolved. The action of air on the fusion also liberated chlorine; but blank determinations in an atmosphere of carbon dioxide proved that under these conditions not a trace of chlorine was evolved. The apparatus employed for a quantitative test of this reaction on perchlorates consisted of a small distilling flask of about 20 cm^3 capacity, into the tubulature of which was ground a piece of glass tubing reaching well into

the bulb and serving for the passage of carbon dioxide. The side neck was sealed to one of two connected Will & Varrentrap absorption bulbs containing a solution of potassium iodide to receive the chlorine. After weighing the perchlorate into the flask and adding a sufficient amount of the powdered double chloride, all air was expelled by carbon dioxide and heat applied till the fused mass was raised considerably above the melting point and kept there for some time. Table V contains the results of a number of experiments performed in this way.

TABLE V.

	$KClO_4$ taken. grms.	$KClO_4$ found. grms.	Error. grms.
(20)	0·0500	0·0438	0·0062—
(21)	0·0500	0·0482	0·0018—
(22)	0·0500	0·0460	0·0040—
(23)	0·1193	0·1175	0·0018—
(24)	0·1039	0·1018	0·0021—
(25)	0·0500	0·0477	0·0023—
(26)	0·1003	0·0946	0·0057—

These results came so close to being quantitative that a little help in the form of free acid seemed all that would be necessary to complete the reaction. But the addition of meta-phosphoric acid to the cooled mass after the fusion in (22) gave no additional evolution of iodine. In (25) gaseous hydrochloric acid was passed in with the carbon dioxide in the hope of meeting the deficiency, but was evidently no improvement. One test in which meta-phosphoric acid was added to the fusion, resulted in such a violent evolution of hydrochloric acid that the whole contents of the flask was forced into the receivers.

The results obtained by substituting (*a*) cadmium iodide and (*b*) anhydrous zinc chloride for the double chloride of aluminum and sodium are recorded in Table VI. In (27) (28) and (29) cadmium iodide was used and the iodine obtained by treating the cooled mass with dilute sulfuric acid (1 : 6) and potassium iodide for the reduction of cadmium oxide in each case added to that of the receivers. In (30) and (31), zinc chloride was employed, but no additional iodine was obtained by treatment with sulfuric acid and potassium iodide.

TABLE VI.

	$KClO_4$ taken. grms.	$KClO_4$ found. grms.	Error. grms.
(27)	0·1000	0·0745	0·0255—
(28)	0·1000	0·0693	0·0307—
(29)	0·1000	0·0679	0·0321—
(30)	0·1000	0·0245	0·0755—
(31)	0·1653	0·1156	0·0497—

In (31) manganous chloride was mixed with the zinc chloride in the proportion of 2 : 1 in the hope of strengthening the reducing action. The black color of the fusion revealed the formation of manganese dioxide, the equivalent of which in iodine was obtained by dissolving the cooled mass in water, adding dilute sulfuric acid and a known amount of ammonium oxalate, titrating the residual oxalate with permanganate solution and calculating the difference into iodine which was added to that obtained by tritrating the contents of the receivers. This addition of manganous chloride to the fusion of the double chloride of aluminum and sodium was forestalled by the necessity of subsequent solution of the fused mass, which contained an impurity in the form of ferric chloride, which of course in the presence of hydriodic acid would be reduced with evolution of iodine.

It was evident from all these results, as well as those obtained by use of other salts not necessary here to record, that fusion with salts of the halogens would not suffice for the complete reduction of perchlorates, or at least would not quantitatively register the result in the halogen liberated. The well known reaction of the oxidation of chromic oxide by fusion with alkaline carbonates was also applied. A combustion tube was used for the fusion, sealed at one end and, after the insertion of chromic oxide with a mixture of sodium and potassium carbonate, restricted at the other end so as to admit a small tube by which carbon dioxide could be entered to expel all air. A blank determination gave no chromate. When 0·1 grm. potassium perchlorate was mixed with an excess of chromic oxide and alkaline carbonate and carefully fused from the top and kept in a state of fusion throughout its length in an atmosphere of carbon dioxide, the fusion subsequently dissolved in water and the chromic oxide removed by filtration, an amount of chromate was obtained on titration equivalent to only 0·0347 grms. of potassium perchlorate.

Powerful as were the various reducing agents employed for the decomposition of perchlorates, they were all successfully resisted, even at the highest permissible temperatures; and if anything is proved by the results of the experiments above recorded, it is that perchloric acid is, in combination, one of the most powerful and stable acids known. Certainly nothing short of high temperatures is capable of overcoming the remarkable affinity by which the oxygen of this acid is held by its salts. At about 400° C the potassium salt fuses with evolution of oxygen, and as a last resort an attempt was made to have the oxygen thus obtained act on hydriodic acid by intervention of nitric oxide. It was the application of this principle that led to the final method, which both as to manipulation and results leaves nothing to be desired.

The method is essentially the collection of the oxygen of the perchlorate; its subsequent passage into an atmosphere of nitric oxide over a strong solution of hydriodic acid, and the titration of the iodine thus liberated with decinormal arsenic in alkaline solution. The apparatus employed consisted of a piece of combustion tubing 10 or 12cm. in length, drawn out at one end to a narrow restriction of length sufficient to prevent the action of the heat on the rubber tubing connecting it with a receiver filled with caustic potash. The tube must of course be cleansed from all organic materials and cannot be safely employed for more than three fusions. A platinum boat (porcelain fusing to the glass) served for the introduction of the perchlorate to the combustion tube, and in order to bring about a gradual and quiet fusion the perchlorate was covered with a small amount of an equal mixture of dry and pure sodium and potassium carbonates. Carbon dioxide obtained from a Kipp generator, the acid and marble of which had been previously boiled to expel all traces of air, and to which a little cuprous chloride had been added to take up any oxygen which might be absorbed from the top, was passed through a solution of iodine in potassium iodide to remove a trace of reducing agent which it was found to contain, and then washed with potassium iodide solution before being used. The larger end of the combustion tube was closed with a perforated rubber stopper by which it was attached to the carbon dioxide apparatus. After all air had been expelled from the inclined tube by means of carbon dioxide, it was connected by a short glass capillary and vacuum tubing joints with the receiver, into which about 50 to 100 cm^3 of gas was allowed to flow before the combustion was started and thus when only a small but inevitable bubble remained insoluble in the caustic potash the complete removal of air was indicated. To prevent the caustic potash from drawing into the combustion tube, a little more carbon dioxide was entered, when the current was closed by a pinch cock on the side towards the generator and heat gradually applied—with perforated asbestos cards on either side to check its radiation to the rubber—and continued till the contents of the platinum boat was in a quiet state of fusion. By lowering one of the bulbs of the caustic potash receiver, the oxygen was evolved under slightly diminished pressure and thus the chances of loss decreased. Then the tube was again inclined and carefully annealed while a current of carbon dioxide carried all of the oxygen into the receiver, which was then closed and disconnected. As a receiver, two leveling bottles were found vastly superior to a burette; the glass stop-cocks of the latter giving continual trouble by the action of the caustic potash upon them. I found that gas could be removed from a leveling bottle with-

out the loss of a particle. if a perforated rubber stopper containing a capillary tube, which reached just even with the narrower end, was by a slight twist forced tightly into the neck of the bottle. In this way a regular funnel shape was obtained and the oxygen could be withdrawn without the slightest bubble remaining. The other end of the capillary was fitted with a short piece of vacuum tubing and screw pinch-cock, which worked incomparably better than the glass stop-cocks. The larger capacity of the bottle was favorable for the volume of oxygen evolved and its shape offered superior facilities for the absorption of carbon dioxide.

For the action of the oxygen on hydriodic acid through the medium of nitric oxide, various devices were tested. Passing it directly into nitric oxide over a solution of hydriodic acid in a Hempel absorption bulb was found to yield low and irregular results, due doubtless to the formation of nitric acid wherever the nitrogen tri-oxide, or per-oxide as the case might be, met water in which the hydriodic acid had been exhausted; as, for instance, along the sides of the bulb. Shaking the bulb as the oxygen entered improved the action, but was not sufficient. It was evident that for a complete action, the hydriodic acid solution must be strong and on the spot where the higher oxide of nitrogen is formed; and to avoid excessive use of the iodide the volume of water must be kept at a minimum. Letting a solution of hydriodic acid saturated with nitric oxide flow slowly into the Hempel bulb in which the oxygen was contained over water, was so slow in its action that a quantitative test was not applied. The plan of mixing the two gases under a strong solution of hydriodic acid by means of two capillaries with adjoining openings, was more effective and rapid, but it was wasteful of nitric oxide, which for complete action would have to flow in continual excess, whereas only a small amount of nitric oxide would really be necessary for the reaction, since it could be used and reused for the transfer of free oxygen to the hydriodic acid. A simple piece of apparatus was then devised to meet all these conditions. It consisted of a 100 cm^3 bulb pipette, cut off short at either ends with stop-cocks sealed to both stubs. The delivery tube of one of the stop-cocks was cut off rather short after being tapered and restricted so as to hold a rubber connecter tightly, while the other delivery tube was left long enough to reach to the bottom of an Erlenmeyer beaker. It is a convenience to have these conducting tubes 3 or 4^{mm} in diameter rather than capillaries, since for the various connections all air may be expelled from them by displacement with water, which is easily accomplished by using a long nozzled wash bottle. By attaching the shorter end to an ordinary water pump the air was partially exhausted when the stop-cock

was closed and the bulb disconnected and lowered into a solution of hydriodic acid of approximately known strength, obtained by acidifying potassium iodide with hydrochloric acid. When the desired amount of liquid had been drawn in, the stop-cock was closed and connection made with the carbon dioxide, by which all residual air was expelled. Then the bulb, held so as to prevent the escape of the liquid, was again exhausted by attachment to the pump. After about $10cm^3$ of nitric oxide were admitted, attachment was made to the receiver containing the oxygen, which was allowed to enter slowly under the diminished pressure within the bulb, and with continous shaking of the contents of the latter. The latter precaution is essential to the process, as otherwise there is imperfect distribution of the hydriodic acid and the danger of forming nitric acid. But when the solution of hydriodic acid is kept strong and the shaking continued while the oxygen enters and for a minute or two afterward, depending on the rapidity with which it was admitted, the oxygen may be allowed to enter quite rapidly without any fear of imperfect action. The oxygen being immediately utilized, the partial vacuum is effected only by the heat generated, which is scarcely noticeable. As a rule the bulb and contents were well cooled before the oxygen was admitted.

It is necessary of course to prevent the access of air into the bulb until the acid has been neutralized, to accomplish which, without loss of iodine, potassium carbonate must be used, at least for the end reaction. To remove the contents of the bulb for titration, the two delivery tubes were filled with water, after removing all sodium hydrate from the one through which the oxygen was entered; the shorter end connected to a supported funnel containing a saturated solution of bi-carbonate and the longer one inserted into an Erlenmeyer beaker containing a saturated solution of bicarbonate in amount sufficient—as previously determined—to neutralize all the acid taken. By opening that stop-cock the delivery tube of which reaches below the liquid in the beaker, the bi-carbonate is drawn in by the partial vacuum, with liberation of sufficient carbon dioxide to force all the liquid out. Owing to the consequent effervescence as the liquid gains its exit, the flow must be regulated by the stop-cock so as to avoid loss of iodine, which is prevented by inclining the beaker so that the bubbles strike against its side instead of being allowed to splatter out of the opening. To wash out the bulb, it is raised almost horizontally, so as to prevent the liquid from running through, and the upper stop-cock opened to admit the bicarbonate from the funnel. Both stop-cocks are then closed, the bulb disconnected and agitated, after which it may be washed with water and admission of air

without any fear of liberating more iodine. An excess of decinormal arsenic is then run into the beaker and titrated back with iodine.

The many little precautions essential to note for the manipulation are in practice accomplished in a few moments. Seven determinations (not counting one which was all but completed, when an accident terminated it) from the weighing of the perchlorate to the titration, were completed in one day; and the results recorded in Table VII show with what reliability. In making the series of experiments recorded in Table VII, it was found expeditious to have a partial vacuum always accessible instead of waiting each time for the exhaustion. This was obtained by connecting a vacuum flask with a two-holed stopper to an ordinary water pump, and having the other perforation fitted with a glass stop-cock. The bulb was merely attached to the vacuum by a piece of rubber tubing; the stop-cock opened and closed immediately, by which means a sufficient exhaustion was secured. To have the vacuum always in readiness a valve, described in a former article of mine,* was placed in the rubber leading to the pump, and when lubricated with glycerine would hold the vacuum perfectly. The nitric oxide employed was supplied by a Kipp generator, in which globules of copper were acted upon by nitric acid mixed with an equal volume of water. To purify the gas evolved from any possible trace of the higher oxides, it was first passed through an acidified solution of potassium iodide in Geissler absorption bulbs, the latter one of the three being alkaline. This method of generating nitric oxide in a Kipp generator (preferably charged with dilute acid and kept warm by immersion in hot water when large amounts of the gas are to be drawn at frequent intervals) was devised by Professor Gooch, by whom it has been employed for some time. It is automatic and eminently satisfactory. The hydriodic acid was obtained from a solution of potassium iodide containing one gram in ten cubic centimeters; thirty cubic centimeters being taken for each experiment, and acidified with the required amount of hydrochloric acid immediately before using, so as to prevent any liberation of iodine by the oxygen of the air. In those experiments in which more than this amount of potassium iodide was employed a correspondingly stronger solution of the latter was used, so that the volume of water was in all cases thirty cubic centimeters.

* This Journal, 1, p. 132.

TABLE VII.

	$KClO_4$ taken. grms.	KI taken. grms.	HCl taken. cm^3	$KClO_4$ found. grms.	Error. grms.
(32)	0·1000	3·	3·	0·1003	0·0003+
(33)	0·1000	3·	3·	0·1006	0·0006+
(34)	0·1000	3·	3·	0·0998	0·0002−
(35)	0·1000	4·	4·	0·1003	0·0003+
(36)	0·1000	3·	3·	0·1003	0·0003+
(37)	0·1000	3·	4·	0·0999	0·0001−
(38)	0·1000	3·	3·	0·1003	0·0003+
(39)	0·1000	3·	4·	0·1001	0·0001+
(40)	0·1500	3·	4·	0·1493	0·0007−
(41)	0·2000	6·	6·	0·1999	0·0001−
(42)	0·2000	6·	6·	0·2009	0·0009+
(43)	0·0100	3·	3·	0·0099	0·0001−
(44)	0·0100	3·	3·	0·0100	0·0000
(45)	0·0000	3·	3·	0·0003	0·0003+

In experiments (40) and (43) during a momentary pause in the shaking of the bulb during the absorption, a black deposit of iodine began to form on the glass, and the result proves the importance of the precaution previously given, that the hydriodic acid should be kept hurling about the bulb until the action is completed. The blank determination (45) shows a constant error of the process which is about 0·0003+ and will be seen to correspond very closely to the average error of the determination. The cause is doubtless to be attributed to the trace of air which may remain in the bulb or be dissolved in the water. Since it can easily be determined and the correction made, it does not detract in any degree from the reliability of the determination.

To determine perchloric acid associated with other oxidizing agents it is only necessary to treat the mixture with the reagents which this investigation and the one referred to has shown to accomplish the reduction without affecting the perchlorate; subsequently evaporating to dryness and treating the residue according to the above process, viz., by heating in a current of carbon dioxide until decomposition is complete; collecting the oxygen over caustic potash; allowing it to enter a partial vacuum bulb containing a solution of potassium iodide, hydrochloric acid and nitric oxide under constant agitation; and determining by means of a standard solution of arsenic the amount of iodine set free. The method is proving applicable also to the determination of oxygen in air or wherever it may be obtained in the free state, unless diluted to such an extent with other gases that the vacuum would be filled by the diluent; even this contingency could be met by enlargement of the absorption bulb.

Many helpful suggestions are to be credited to Professor Gooch.

Art. XXXI.—*On an Occurrence of Copper in Western Idaho;* by R. L. Packard.

The Seven Devils is the name (of rough frontier origin) given to a range or group of mountains on the extreme western border of Idaho where that state is separated from Oregon by the Snake River on its northerly course to empty into the Columbia. The river runs through a deep gorge as it passes the mountains, the east side of which is formed by members of the Seven Devils group, while the western side or wall, which is very precipitous, is formed by a range on the Oregon side called the Eagle Mountains. The few sharply pointed, precipitous peaks which are the Seven Devils proper and have given their name to the whole group have an altitude of over seven thousand feet. They are of igneous origin and attracted the attention of prospectors many years ago, who found gold in the streams issuing from their domain and copper in the mountains adjoining them.

The only occurrence of copper of importance which has so far been exploited is found in the southern part of the range and is confined to the neighborhood of a body of whitish granitic rock of very considerable but not yet determined extent. The copper occurs as bornite and the principal mine of the locality is named the Peacock, from the nature of the ore. The igneous rock, which evidently has a genetic relation to the copper deposits, has the general appearance of a granite and has always been so called. It is grayish white in color, and in hand specimens does resemble a biotite granite without muscovite. It weathers into rounded blocks which are sometimes met with in isolated groups, and at one point on the wagon road leading up from the Snake River to the copper mines, and about a mile from the latter, the head of a small ravine is filled with bowlders of this rock several feet in diameter which give the appearance of having been purposely rolled into the place. Water runs down among these rocks at some distance out of sight.

The whitish rock, where exposed, and in the bowlders, is seen to contain areas of a darker color which vary in size from two or three inches to as many feet in diameter and impress one at first as being inclusions of some other rock.

This igneous rock, one would say, was evidently the cause, if not the source, of the copper deposits found on its contact and in veins in its substance, and it became a matter of curiosity to examine its mineralogical and chemical character. Specimens were, accordingly, procured from points about a

mile and a half apart, one on the wagon road leading to the mines (at the White Monument hill), and the other at the Victoria mine on the northern limit of the mines where the mountain descends abruptly to form one side of Deep Creek cañon. The slightly darker appearance of the rock at the latter place indicates that its composition varies somewhat from point to point. It is also an assumption that the whole mass is continuous for the distance mentioned. Indeed a flow of basalt intervenes at one place, but the extent of the flow is undetermined.

The thin sections from these specimens show that the rock has the following structure and composition. The structure is that of granite. The stout, tabular, triclinic feldspars largely predominate. Many of them are turbid. Interstitial quartz is present. The ferromagnesian minerals are hypidiomorphic, green, pleochroic hornblende, and some brown biotite, also limited by the adjoining feldspars. Apatite crystals, zircons, and some isometric granules of ore were also observed. A section from one of the inclusions described above showed the same mineralogical composition as the lighter-colored rock but the structure shows cataclastic areas. Green hornblendes, with inclusions, and triclinic feldspars, appear in the midst of the comminuted crystals. The section also shows biotite, with inclusions, limited by the adjoining feldspars, and the ore particles are much more numerous than in the lighter-colored rock. Zonal structure of the feldspars was noticeable in both sections.

The rock, therefore, as shown by these sections, is a diorite. Its analysis gave:

Ignition	·90
SiO_2	53·98
Al_2O_3, Fe_2O_3	27·64
CaO	7·03
MgO	4·63
Na_2O	4·51
K_2O	1·75
	100·44

The analysis, although only partial, is sufficient to show the basic character of the rock; and the excess of soda over potash, together with the high percentage of lime, confirms the microscopical determination of the predominance of the soda-lime feldspars over orthoclase.

The specimen from the Victoria mine was taken within a foot or two of a copper vein (bornite), and the section, viewed without the analyzer, shows fissures stained bluish-green by

copper solution. In the thin section brown biotite and quartz are much more abundant than in the specimens just described, but the predominating plagioclase feldspars and the fragments of green hornblende indicate the dioritic character of the rock. The biotite is seen undergoing bleaching and an alteration to a green mineral.

Diorite must also occur in the mountains north of the copper mines, for a specimen taken from a mass of rocky *débris* on the trail which passes through the Seven Devils, and perhaps eight miles from the mines, proved to be diorite when examined in thin section.

The diorite of the copper locality is bounded on its western side by a zone of a garnet-epidote rock and the bornite is found in this rock in kidneys and larger masses. At the Peacock mine the ore and garnet rock appeared to dip towards the diorite. West of the garnet rock appears an igneous rock the character of which is yet undetermined. Crystalline limestone accompanied with garnet rock crosses the diorite to the northeast at about a mile south of the Peacock mine. Mines are established at this contact also. The distance from end to end of the copper belt may be three miles or more in a direct line. The copper ore, except at the Victoria mine, is associated with the metamorphic- or metamorphosed-garnet rock, which is, in some places, more than a hundred feet thick, but at the Victoria mine the bornite occurs in a vein which is in the body of the diorite although near its contact with an eruptive rock and outside of the garnet belt.

Copper and iron (as sulphides forming bornite) are not the only metals due to the diorite. The bornite carries silver, sometimes up to twenty ounces per ton, and native gold is occasionally found in it. The gravel of the diorite is washed for gold, and a quartz vein carrying a little gold is "located" near the contact of diorite and basalt. A little galena has been noticed. It was at this place that the molybdate of lime, described as powellite,* was found four years ago.

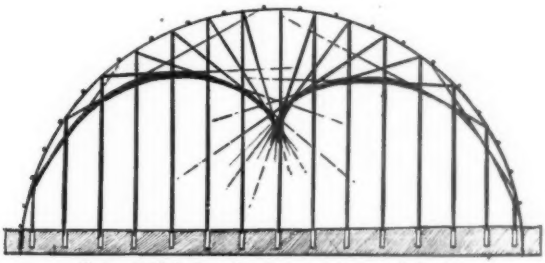
* This Journal, xli, 138, 1891.

Washington, D. C., June 19, 1895.

Art. XXXII.—*Demonstration of Caustics;* by Robert Williams Wood.

The caustic surfaces by reflection from concave mirrors can be shown geometrically to be the paths to which all the reflected rays are tangent. A simple way of demonstrating this experimentally is the following: A strip of thin steel about 16 inches long, by 1 in width, is polished on one side until it has a good mirror surface. An accurate optical surface is of course unnecessary. The curve, for example a semi-circle, whose caustic is to be shown is drawn on a piece of photographic printing paper, and pinned down onto a board with a dozen or more pins, stuck vertically through the line. The steel strip is bent into this arc, and pressed firmly against the row of pins, the ends being held in place by a couple of small nails. In front of the steel arc across the diameter is set up a strip of Bristol board with a number of vertical slits, about $\frac{1}{16}$ of an inch wide, and half an inch apart. On setting up the board in strong sun-light, in a plane pointing a little below the sun, the parallel rays passing through the slits trace their course on the paper, are reflected and trace their reflected paths also, which in the case of a semi-circular mirror will all be found to be tangent to an epicycloid. The complete curve can be traced by raising the grating for a moment or two. During the exposure it is best to bridge over the steel arc with a piece of card-board to exclude diffused daylight.

1.

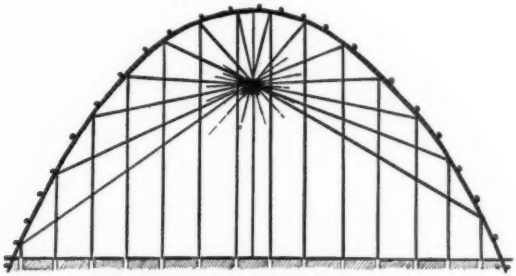


Epicycloidal Caustic showing tangential rays.

The accompanying drawings (figs. 1 and 2) are copied directly from the photographic tracings, and are of course negatives, the black lines representing the paths traced by the luminous rays. It is not easy to get a parabolic surface that shall bring all the rays to a focus, each side of the curve being apt to have a focus of its own; but a little careful manipulation and changing the position of the pins a trifle, will usually

bring them together. The card-board screen is shown (tipped over) in the drawing of the epicycloidal caustic.

2.



Reflection from a Parabolic Surface.

The axis of the reflecting surface must of course point directly at the sun, or rather a little below it. If the paper is fairly sensitive the exposure need not be over a minute or two, and the motion of the sun will give no trouble. If a longer exposure is necessary the mirror may be turned a trifle from time to time.

These phenomena are adapted to projection, by employing a nearly parallel beam thrown along the screen, either directly or by means of a mirror. The reflecting surface and the slits should be much larger than the ones used for photographic representation.

Berlin, Germany.

Art. XXXIII.—*The Spectrum of Helium*;* by William Crookes, F.R.S.

In the Chemical News for March 29th last (vol. lxxi, p. 151) I published the results of measurements of the wave-lengths of the more prominent lines seen in the spectrum of the gas from clèveite, now identified with helium. The gas had been given to me by the discoverer, Professor Ramsay; and being from the first batch prepared, it contained other gases as impurities, such as nitrogen and aqueous vapor, both of which gave spectra interfering with the purity of the true helium spectrum. I have since, thanks to the kindness of Professors Ramsay and J. Norman Lockyer, had an opportunity of examining samples of helium from different minerals and of con-

* From an advanced proof sent by the author.

siderable purity as far as known contamination is concerned. These samples of gas were sealed in tubes of various kinds and exhausted to the most luminous point for spectrum observations. In most cases no internal electrodes were used, but the rarefied gas was illuminated solely by induction, metallic terminals being attached to the outside of the tube.* For photographic purposes, a quartz window was attached to the end of the tube, so that the spectrum of the gas could be taken "end on."

My examinations have chiefly been made on five samples of gas.

1. A sample from Professor Ramsay in March last. Prepared from clèveite.

2. A sample from Professor Ramsay in May last. Prepared from a specimen of uraninite sent to him by Dr. W. F. Hillebrand. Gas obtained by means of sulphuric acid; purified by sparking.

3. A sample from Professor Ramsay in June last. Prepared from bröggerite.

4. A sample from Professor Lockyer in July last. Prepared by a process of fractional distillation from a sample of bröggerite sent to him by Professor Brögger.

5. A sample of gas from Professor Ramsay "helium purissimum." This was obtained from mixed sources, and had been purified to the highest possible point.

In the following table the first four samples of gas will be called: 1. "clèveite, R."; 2. "uraninite, R."; 3. "bröggerite, R."; and 4. "bröggerite, L." Only the strongest of the lines, and those about which I have no doubt, are given. The wave-lengths are on Rowland's scale.

The photographs were taken on plates bent to the proper curvature for bringing the whole spectrum in accurate focus at the same time. The spectrum given by a spark between an alloy of equal atoms of mercury, cadmium, zinc, and tin, was photographed at the same time on the plate, partially overlapping the helium spectrum; suitable lines of these metals were used as standards. The measurements were taken by means of a special micrometer reading approximately to the $\frac{1}{100,000}$th inch, and with accuracy to the $\frac{1}{10,000}$th of an inch. The calculations were performed according to Sir George Stokes's formula, supplemented by an additional formula kindly supplied by Sir George Stokes, giving a correction to be applied to the approximate wave-lengths given by the first formula, and greatly increasing the accuracy of the results.

* Journal of the Institution of Electrical Engineers, Part 91, vol. xx, Inaugural Address by the President, William Crookes, F.R.S., Jan. 15th, 1891.

Wave-length.	Intensity.	
7065·5	5	A red line, seen in all the samples of gas, Young gives a chromospheric line at 7065·5.
6678·1	8	A red line, seen in all the samples of gas. Thalén gives a line at 6677 and Lockyer at 6678. Young gives a chromospheric line at 6678·3.
5876·0	30	The characteristic yellow line of helium, seen in all the samples of gas. Thalén makes it 5875·9, and Rowland 5875·98. Young gives a chromospheric line at 5876.
5062·15	3	
5047·1	5	A yellow-green line, only seen in "helium puriss." and in "bröggerite, R," and "L." Thalén gives the wave-length as 5048.
5015·9	7	A green line seen in all the samples of gas. Thalén gives the wave-length 5016. Young gives a chromospheric line at 5015·9.
4931·9	3	
4922·6	10	A green line, seen in all the samples of gas. Thalén gives the wave-length 4922. Young gives a chromospheric line at 4922·3.
4870·6	7	A green line, only seen in "uraninite, R." Young gives a chromospheric line at 4870·4.
4847·3	7	A green line, only seen in "uraninite, R." Young gives a chromospheric line at 4848·7.
4805·6	9	A green line, only seen in "uraninite, R." Young gives a chromospheric line at 4805·25.
4764·4	2	There is a hydrogen line at 4764·0.
4735·1	10	A very strong greenish blue line, only seen in "uraninite, R."
4713·4	9	A blue line, seen in all the samples of gas. Thalén's measurement is 4713·5. Young gives a chromospheric line at 4713·4
4658·5	8	A blue line, only seen in "uraninite, R."
4579·1	3	A faint blue line, seen in "uraninite, R." Lockyer gives a line at 4580, from certain minerals. I can see no traces of it in the gas from bröggerite. A hydrogen line occurs at 4580·1.
4559·4	2	Young gives a chromospheric line at 4558·9.
4544·1	5	
4520·9	3	A faint blue line, seen in "uraninite, R." Lockyer gives a line at 4522, seen in the gas from some minerals. Young gives a chromospheric line at 4522·9. It is absent in the gas from bröggerite.
4511·4	5	A blue line, seen in "uraninite, R," but not in the others. It is coincident with the strong head of a carbon band in the CO_2 and Cy spectrum.
4497·8	2	There is a hydrogen line at 4498·75.

Wave-length.	Intensity.	
4471·5	10	A very strong blue line, having a fainter line on each side, forming a close triplet. It is a prominent line in all the samples of gas examined. Young gives the wave-length 4471·8 for a line in the chromosphere, and Lockyer gives 4471 for a line in gas from bröggerite.
4435·7	9	Seen in "helium puriss."
4437·1	1	Young gives a chromospheric line at 4437·2.
4428·1	10	These two lines form a close pair. I can only see them in "uraninite, R." No trace of them can be seen in the gases from other sources. Young gives chromospheric lines at 4426·6 and 4425·6.
4424·0	10	
4399·0	10	A strong line, only seen in "uraninite, R." Absent in the gas from the other sources. Lockyer gives a line at 4398 in gas from certain minerals. Young gives a chromospheric line at 4398·9.
4386·3	6	Seen in all the samples of gas. Young gives a chromospheric line at 4385·4.
4378·8	8	These two lines form a pair seen in "uraninite, R," but entirely absent in the others.
4371·0	8	
4348·4	10	Seen in "uraninite, R." Lockyer finds a line at 4347 in the gas from certain minerals.
4333·9	10	Probably a very close double line. Seen in "uraninite, R" and "clèveite, R." Not seen in the other samples. Lockyer gives a line in the gas from certain minerals at 4338.
4298·7	6	Only seen in "uraninite, R." Young gives a chromospheric line at 4298·5.
4281·3	5	Only seen in "uraninite, R."
4271·0	5	Only seen in "uraninite, R." The strong head of a nitrogen band occurs close to the line.
4258·8	7	Seen in all the samples of gas.
4227·1	5	Only seen in "uraninite, R." Young gives a chromospheric line at 4226·89.
4198·6	9	These three lines form a prominent group in "uraninite, R," they are very faint in "clèveite, R," and in "bröggerite, L," but are not seen in "bröggerite, R."
4189·9	9	
4181·5	9	
4178·1	1	An extremely faint line. Lockyer gives a line at 4177, seen in the gas from certain minerals, and Young gives a chromospheric line at 4179·5.
4169·4	6	Seen in "helium puriss."
4157·6	8	A strong line in "uraninite, R," very faint in bröggerite, R," and "L," not seen in "clèveite, R."
4143·9	7	Strong in "clèveite, R," in "helium puriss.," and in "bröggerite, L." It is faint in "uraninite, R," and not seen in "bröggerite, R." Lockyer gives a line at 4145 in gas from certain minerals.

Wave-length.	Intensity.	
4121·3	7	Present in all the gases except "clèveite, R."
4044·3	9	Present in "uraninite, R," and "clèveite, R." Absent in the others.
4026·1	10	These lines form a very close pair, seen in all the samples of gas, except "bröggerite, R."
4024·15	6	Lockyer find a line in bröggerite gas at 4026·5.
4012·9	7	Seen in all the samples of gas.
4009·2	7	Seen in "helium puriss."
3964·8	10	The center line of a dense triplet. Only seen in "clèveite, R," in "helium puriss.," and "bröggerite, L." Hale gives a chromospheric line at 3964.
3962·3	4	Seen in all the samples of gas.
3948·2	10	Very strong in "uraninite, R," very faint in "clèverite, R," and not seen in the others. Lockyer finds a line in gas from bröggerite at 3947. There is an eclipse line at the same wave-length.
3925·8	2	Seen in "helium puriss."
3917·0	2	Seen in "helium puriss."
3913·2	4	Only seen in "uraninite, R," and "helium puriss." Hale gives a chromospheric line at 3913·5.
3890·5	9	A very strong triplet, seen in all the samples of gas. Lockyer finds a line having a wave-length 3889 in gas from bröggerite. Hale gives a chromospheric line at 3888·73. There is a strong hydrogen line at 3889·15.
3888·5	10	
3885·9	9	
3874·6	6	Only seen in "uraninite, R."
3867·7	8	Seen in "helium puriss."
3819·4	10	Seen in all the samples of gas. Deslandres gives a chromospheric line at 3819·8.
3800·6	4	Seen in "helium puriss."
3732·5	5	Seen in "helium puriss." Hale gives a chromospheric line at 3733·3.
3705·4	6	Seen in all the samples of gas. Deslandres gives a chromospheric line at 3705·9.
3642·0	8	Only seen in "uraninite, R."
3633·3	8	Seen in "helium puriss."
3627·8	5	Only seen in "uraninite, R."
3613·7	9	Seen in "helium puriss."
3587·0	5	Seen in "helium puriss."
3447·8	8	Seen in "helium puriss."
3353·8	5	Seen in "helium puriss."
3247·5	2	Seen in "helium puriss."
3187·3	10	The center line of a close triplet. Very faint in "clèveite, R," and "uraninite, R," and strong in "helium puriss." and in "bröggerite, L." It is not seen in "bröggerite, R."

Wave-length.	Intensity.	
2944·9	8	A prominent line, only seen in "helium puriss." and in "bröggerite, L."
2536·5	8	Seen in "helium puriss." A mercury line occurs 2536·72.
2479·1	4	Seen in "helium puriss."
2446·4	2	Seen in "helium puriss."
2419·8	2	Seen in "helium puriss."

Some of the more refrangible lines may possibly be due to the presence of a carbon compound with the helium. To photograph them a long exposure, extending over several hours, is necessary. The quartz window has to be cemented to the glass with an organic cement, and the long-continued action of the powerful induction current on the organic matter decomposes it, and fills the more refrangible end of the spectrum with lines and bands in which some of the flutings of hydrocarbon, cyanogen, and carbonic anhydride are to be distinguished.

There is a great difference in the relative intensities of the same lines in the gas from different minerals. Besides the case mentioned by Professor Kayser of the yellow and green lines 5876 and 5016, which vary in strength to such a degree as to render it highly probable that they represent two different elements, I have found many similar cases of lines which are relatively faint or absent in gas from one source and strong in that from another source.

Noticing only the strongest lines which I have called "intensity 10," "9," or "8," and taking no account of them when present in traces in other minerals, the following appear to be special to the gas from uraninite:

4735·1	4424·0	4371·0	4189·9	3948·2
4658·5	4399·0	4348·4	4181·5	3642·0
4428·1	4378·8	4198·6	4157·6	

The following strong lines are present in all the samples of gas:

7065·5	4922·6	4258·8	3885·5
6678·1	4713·4	4012·9	3885·9
5876·9	4471·5	3962·3	3819·4
5015·9	4386·3	3890·5	3705·4

The distribution assigned to some of the lines in the above tables is subject to correction. The intensities are deduced from an examination of photographs, taken with very varied exposures; some having been exposed long to bring out the fainter lines, and some a short time to give details of structure in the stronger lines. Unless all the photographs have been exposed for the same time, there is a liability of the relative

intensities of lines in one picture not being the same as those in another picture. Judgment is needed in deciding whether a line is to have an intensity of 7 or 8 assigned to it; and as in the tables I have not included lines below intensity 8, it might happen that another series of photographs with independent measurements of intensities would in some degree alter the above arrangement.

In the following table I have given a list of lines which are probably identical with lines observed in the chromosphere and prominences:

Wave-length observed of helium.	Intensities.	Wave-lengths of chromospheric lines,* Rowland's scale.
7065·5	10	7065·5
6678·1	10	6678·3
5876·0	30	5876·0
5015·6	6	5015·9
4922·6	10	4922·3
4870·6	7	4870·4
4847·3	7	4848·7
4805·6	9	4805·25
4713·4	9	4713·4
4559·4	2	4558·9
4520·9	3	4522·9
4471·5	10	4471·8
4437·1	1	4437·2
4428·1	10	4426·6
4424·0	10	4425·6
4399·0	10	4398·9
4386·3	6	4385·4
4298·7	6	4298·5
4227·1	5	4226·89
4178·1	1	4179·5
3964·8	10	3964·0 H.†
3948·2	10	3945·2 H.
3913·2	4	3913·5 H.
3888·5	10	3888·73 H.
3819·4	10	3819·8 D.
3732·5	5	3733·3
3705·4	6	3705·9 D.

* A Treatise on Astronomical Spectroscopy, by Dr. J. Scheiner, translated by E. B. Frost, Boston, 1894.

† The wave-lengths to which the initials D. and H. are added are wave-lengths of lines photographically detected in the spectrum of the chromosphere by Deslandres (D) and Hale (H). Their photographs do not extend beyond wave-length 3630. Professor Lockyer (Roy. Soc. Proc., vol. lviii, p. 116, May, 1895) has already pointed out fourteen coincidences between the wave-lengths of lines in terrestrial helium and in those observed in the chromosphere, the eclipse lines, and stellar spectra.

ART. XXXIV.—*On the Igneous Rocks of the Sweet Grass Hills, Montana;* by W. H. WEED and L. V. PIRSSON.

IN northern Montana, the broad expanse of the great plains that lie east of the Rocky Mountain Cordillera is interrupted by a group of peaks, rising abruptly from the general level near the Canadian boundary line. These peaks, forming three isolated mountain masses, are known as the Sweet Grass Hills, or Three Buttes. Their sharp outlines and isolated position attract attention from every point of view, while recent discoveries of copper leads and ores of the precious metals, together with the excellence of the coal beds upon their flanks, have caused an influx of prospectors from the mining regions of the state.

The locality is now easily reached, as a tri-weekly stage runs from Shelby junction, where the Great Falls and Canada road crosses the Great Northern Railway, to the settlements on Birch Creek. The East and West Buttes are twenty miles apart, the Middle Butte lying to the south about midway between. The summits reach a height of 3,000 feet above the plains, and each butte is the center of a small mountain area whose verdure-clad slopes, copious springs and flowing streams are in strong and pleasing contrast to the desolate monotony of "Lonesome" prairie to the south. Through the kindness of Dr. G. M. Dawson, Assistant Director of the Canadian Geological Survey, who is the only geologist that has explored the Hills, the authors have been allowed to examine a number of specimens of the volcanic rocks constituting the central cores of these interesting mountain masses. The general geology of the Sweet Grass Hills has been described by Dr. Dawson,* from whose report the following notes have been taken.

The three buttes constituting the Sweet Grass Hills occur in the center of a broad and low anticlinal uplift that stretches for many miles parallel to the Rocky Mountain front, from which it is separated by a broad, shallow, synclinal basin. Each mountain mass consists of a core of igneous rock surrounded by Cretaceous beds uptilted at high angles, whose inclination gradually becomes less and less away from the eruptive rock, merging into the horizontal strata of the plains.

The igneous rocks forming the central masses of these mountains, though very dense and compact, are seldom seen in solid masses, since they break readily into irregular, angular fragments from a few inches to two feet across, forming debris

* Report Canadian Geol. Survey, 1882–4, C, pp. 16, 45. "Report upon country in vicinity of the Bow and Belly rivers, Northwest Territory."

piles that obscure all exposures. Dikes are occasionally found in the foot-hills or surrounding plains country, and appear to have a direction radiant from the higher peaks.

The East Butte, whose highest peak reaches an elevation of 6,200 feet above the sea, consists of four main points arranged in an irregular square. The conical northwestern peak is the most prominent; it is connected by a high ridge with the round-topped southwestern peak. The sedimentary rocks consist of yellowish and gray sandstones and black shales of Colorado Cretaceous, or Belly River (Montana?) age, the latter rocks being carved along the valleys into castellated shapes whose fluted surfaces, balcony ledges and intricate fret work, form most picturesque and attractive forms. These sedimentary rocks dip away from the Butte in all directions; the harder strata form more or less continuous ridges separated by depressions carved in the shales, and encircling the mountain. Near the igneous rocks the beds are much hardened and altered by contact metamorphism.

The dike rock described herein* occurs as a broken wall, traversing the horizontal sandstones and clays ten miles north of the summit of the East Butte. Its course is east and west.

The West Butte is the largest of the three, and rises to a height of 6,500 feet. It forms a mountainous area with numerous round-topped peaks and ridges separated by deep, precipitous valleys. The highest point is a large, blunt-topped summit with vertical rocky cliffs forming the eastern face. The sedimentary strata, dipping away from the peaks of igneous rock, show considerable contact metamorphism, and large areas of these altered rocks occur in the central portion of the mountain.

The structure here described corresponds closely with that observed in the mountain groups to the south of the Sweet Grass Hills. The Moccasin mountains, two isolated mountain masses, rising above the plains south of the Missouri, near the Judith mountains, consist of igneous cores whose rocks closely resemble those of this region, and are clearly laccolitic in character. Similar laccolites occur in the northeastern part of the Little Belt range, and the eruptive rocks of the outlying mountain groups, the Bear Paw, Little Rocky and Judith ranges, are also, in part at least, laccolitic. At most of the localities, however, the Paleozoic rocks are exposed, the intrusion having occurred in the shales forming the base of the Paleozoic series, whereas the Sweet Grass rocks are all of late Cretaceous age.

The igneous rocks here described are of similar types and correspond closely to those forming the laccolitic mountains just mentioned.

* See description by Dr. Dawson, loc. cit., p. 45.

Quartz Diorite Porphyrite.

This rock is represented by two specimens from West Butte. It is dense, of a dark gray color and thickly spotted with white feldspar phenocrysts. They are generally equidimensional and about 2^{mm} across, but in one specimen examples of twice this size occur. At times they are somewhat elongated and are then arranged in flowage planes showing fluid movements. Occasional small crystals of hornblende up to 4^{mm} in length can be seen. The rock weathers with a brownish crust.

Microscopically the following minerals are observed to be present: Apatite, hornblende, iron ore, plagioclase, orthoclase and quartz.

Plagioclase. As indicated in the hand specimens, this is very abundant as a phenocryst. The crystals are generally well formed and tabular on *b*(010). They are twinned according to the albite and Carlsbad laws. They are usually zonally built and the more basic inner portion shows a perceptible dispersion of the optic axes. They vary in composition from a basic labradorite to a medium acid oligoclase; thus a section in the zone *a*(100) on *c*(001) gave extinctions on either side of the albite twinning line of 26°, while the Carlsbad twin gave 12°, thus showing a basic labradorite approaching bytownite—a determination confirmed on other sections. In these sections the zonal growth is greatly marked and steadily becomes more acid towards the periphery. In another specimen the feldspars are more acid and even approach acid oligoclase.

The hornblende is pretty common in short, stout, ill-formed crystals and is nearly always changed to masses of opacite and chlorite and other decomposition products. It is the usual dark green variety. Twins at times on *a*(100).

The groundmass in which the above minerals lie is a very fine-grained, patchy or micro-poikilitic mixture of quartz and feldspar, the latter usually too much altered or kaolinized for identification but certainly composed in part of orthoclase. The quartz occurs also at times in irregular grains, which rise to the position of small phenocrysts. A greenish-yellowish mineral of the chlorite group occurs very often in cavities arranged in vermicular growths.

Quartz Syenite Porphyry.

This rock is represented by two specimens from East Butte. It is tough and compact, of a pale brown color which changes to a pale green gray on weathered surfaces. This groundmass is very thickly crowded with phenocrysts of feldspar which vary very greatly in size from examples 11^{mm} by 6^{mm} down to some only 0·5^{mm} across. They have the common flesh color of

orthoclase. There are also many little crystals of black augite smaller than the smallest feldspar phenocrysts.

The microscope shows the following minerals present: Zircon, iron ore, apatite, ægerine-augite, oligoclase, orthoclase, anorthoclase and quartz.

The zircon is rare and appears in very small stout columnar crystals. The iron ore is not abundant, but there is a moderate amount of it. The augite is in short, very thick little prisms about 0·5^{mm} long. Prisms and pinacoids are present. It generally contains a pale green diopside core which rapidly passes into a bright green ægirite-augite mantle; often the diopside core is wanting and the crystal passes into deep green ægirite on the exterior, the optical properties suffering a corresponding change. Some examples are changed exteriorly to ferruginous products by alteration. The oligoclase appears in the form of idiomorphic phenocrysts of tabular form or somewhat columnar on the ă axis about 1^{mm} long. Both the Carlsbad and albite twinnings are present. It is a rather common phenocryst. Much more abundant, however, are larger, ill-formed orthoclase crystals which present no unusual features. They commonly show the Carlsbad twin, but a Baveno twin was seen in one case. The anorthoclase is also quite abundant and is frequently intergrown with orthoclase. It contains successive rows or sets of short, excessively fine lamellæ of albite, twinned according to the albite law. It is sharply differentiated from the oligoclase both by the difference in double refraction and by its method of twinning. All three of these feldspars are apt to be collected together into grouped masses. They are slightly kaolinized.

The above phenocrysts lie scattered in a rather fine groundmass composed of allotriomorphic feldspar and quartz. The structure is micro-granitic and the amount of quartz is considerable. The feldspar is mostly alkali feldspar, unstriated, but a certain amount of oligoclase is present in the second generation. Small microlites of a mineral of strong refraction are present which may be of augite.

The systematic position of this rock type is rather peculiar; it is clearly of high silica, alumina and alkalies, and of these latter soda is very largely present. It contains considerable iron, while lime and especially magnesia play but an inconspicuous role. It is closely allied to the granite porphyries by the large amount of quartz in the groundmass, but it does not contain any quartz phenocrysts. On the other hand, the amount of plagioclase present, while not sufficient to throw the rock out of the alkali group, shows tendencies towards diorite porphyrite. Under these conditions it seems most closely allied to the syenitic group of rocks and the name of quartz syenite porphyry is given it.

Minette.

This is shown by a specimen from a dike north of East Butte. It is a dull, dark stone-gray color, filled with phenocrysts of biotite which have a maximum diameter of 5^{mm}. They are very common, and being arranged in an approximately parallel position, they give the rock a facility for cleavage in that plane. The lens shows a pale yellowish augite to be also present.

Under the microscope the following minerals are seen: Apatite, iron ore, biotite, augite, orthoclase and calcite.

The biotite is of a very pale leather-brown color and feebly pleochroic. It has a zonal structure, being invariably bordered by a narrow deep brown rim. The axial angle is extremely small and the axial plane is parallel to an edge of the hexagonal section; it is thus a meroxene. The large plates are greatly embayed and irregular and frequently composed of smaller individuals in parallel position. It thus corresponds precisely to the biotite characteristic of minettes as described by Rosenbusch.* Apatite is not very common. It presents nothing unusual. The iron ore is entirely in the second generation. The augite is in rather large, stout, ill-formed crystals, colorless and with here and there patches of alteration into carbonates. The groundmass in which the phenocrysts lie is composed of a mixture of very fine biotite leaves and shreds, small grains and rods of augite, grains of iron ore and laths of an untwinned feldspar which appears to be orthoclase. The orthoclase laths are at times arranged in rude spherulitic forms. Often among the augite prisms are some that are deep green and strongly pleochroic and extended in an optically negative direction. They must therefore be of ægirite. Between the feldspar laths there frequently appears small formless patches of a colorless isotropic substance that is believed to be glass.

The rock has a porphyritic structure and it is a very typical minette. It is also quite fresh, there being no alteration except in the augite. It contains some fragments of calcite that appear to be foreign to it, as if brought up from rocks below as an inclusion. In it the dark minerals play a preponderating role, the feldspars being present but in comparatively small amount in the groundmass. Its petrological affinities ally it with the syenite-porphyry of East Butte, with which it probably stands in geological relation. From this point of view it is interesting to note the occurrence of the ægirite both in the porphyry and in the minette.

Washington and New Haven, June, 1895.

* Mass. Gesteine, p. 310, 1887.

ART. XXXV.—*On the Distribution and the Secular Variation of Terrestrial Magnetism, No. III;** by L. A. BAUER, PH.D.

As stated in the preceding number, the special object of this communication is to see whether we can refer the *secular variation* to the secular shift of the secondary magnetic dip poles revealed when considering the phenomena of the distribution of terrestrial magnetism.†

If this be the case, its importance cannot be overestimated. The investigation of the phenomenon which has been the source of such perplexity for several centuries—the so-called secular variation, whereby remarkable changes occur in the distribution of the earth's magnetism in the lapse of time—has then entered upon a new stage; for the prime reason that we can now refer the secular variation to shifting magnetic poles that are nearly on the equator and, hence, in a region easily accessible, and in which magnetic observations are continually being made, instead of to magnetic poles in the polar regions where observations are rarely made on account of the difficulty of access.

The magnetic charts published from time to time can represent the distribution in terrestrial magnetism in the equatorial regions fairly well, while that in the polar regions must be more or less guess-work. Hence, the difficulty of locating approximately the *secondary* magnetic dip poles is a minimum in comparison with the assignment of position of those we believe to be in the arctic and antarctic regions.

It behooves us then to look carefully into the matter forming the chief subject of our present inquiry. The problem to be solved I shall state as follows:

What is the secular motion of the secondary magnetic dip poles?

Before entering upon the discussion of this question it will be desirable to state that all the conclusions thus far have been obtained empirically. No theory has been advanced. My purpose hitherto has been to accumulate facts to serve ultimately as a foundation upon which to base a theory. A sufficient number of empirical laws and facts have now been derived to justify and to make desirable the undertaking of a theoretical attack, to be begun in the following number. The results to be given in the present paper are still free from theoretical assumptions. They are facts of pure observation.

* The main results of this paper were presented to the Washington Philosophical Society, May 25, 1895. Abstract in Science, June 21, 1895.

† This Journal, Art. XX, September, 1895.

It will be recalled that we found that the main distribution phenomena could be represented by two rectangular magnetic systems, a polar and an approximately equatorial, the former of about 5 or 6 times the strength of the latter. This conclusion was reached with the aid of the magnetic observations for 1885. Suppose we carry out the same investigation for other dates, shall we reach the same result?

Let us begin with the year 1780, since for this date we possess the earliest fairly reliable isoclinic chart. This chart gives us the approximate distribution of the magnetic dip for that date. It was constructed by Christopher Hansteen.* The first thing to be done is to construct the "isapoclinics" according to the method explained in No. II. For this purpose, I have scaled the dips for points 20° distant in longitude and in latitudes $+60°$, $\pm 40°$, $\pm 20°$ and 0°. The data for latitude 60° S. could not be safely obtained and hence the "isapoclinics" are not extended beyond 40° S. For the regions of the two foci (secondary dip poles), I have made a few closer scalings.

Having obtained the data as based upon observation, the computed dip I_c is again derived with the aid of equation:

$$\tan I_c = 2 \tan \varphi,$$

φ being the geographical latitude. It will be remembered that this is the dip that would prevail at the place where the latitude is φ if the earth were uniformly magnetized about the geographical axis and *were at rest.* The departure of the actual (or observed) dip from this computed dip is:

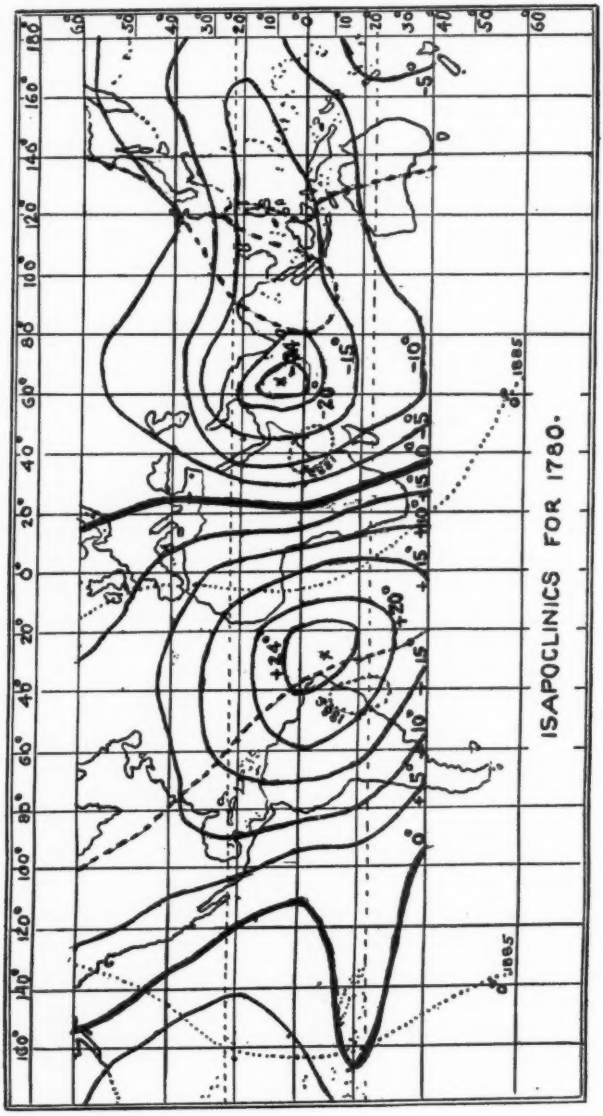
$$\triangle I = I_{obs'd} - I_{comp'd} = I_o - I_c.$$

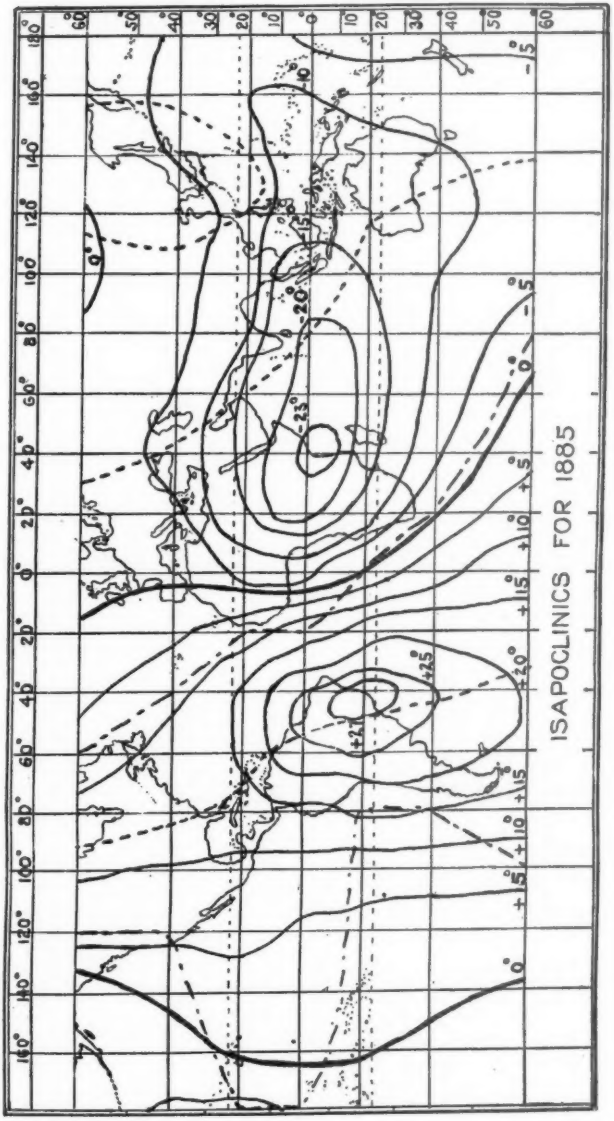
These differences we form for all the scaled values, plot them on a map in their true geographical position, and finally draw lines through all the places having the same $\triangle I$, or departure, paying due regard to sign. The lines obtained thus I have termed lines of equal-departing dip or, briefly, isapoclinics. The result for 1780 is given on the diagram, page 316. For the sake of convenience in comparison the same curves for 1885 are reproduced from No. II.†

It will be seen that the main result is the same for both dates. The secondary polarization is again nearly equatorial. Hence, the final conclusion of No. II is borne out by this early date. We shall see later that this is also true for an intermediate year, 1829.

* The chart will be found in the Atlas to his "Untersuchungen über den Magnetismus der Erde, Christiania, 1819. A reduced copy is given in Neumayer's "Atlas des Erdmagnetismus," Gotha, 1891, plate No. 41.

† In the reproduction the isapoclinic + 25° has been slightly improved.


ISAPOCLINICS FOR 1780.
d. 1885
d. 1885


ISAPOCLINICS FOR 1885

The plus isapoclinics are again simpler in form than the minus ones, and from this fact one could argue that if we were to construct the "equiabspotentials," the foci of the plus equal-departing potentials would fall more closely together with that of the plus isapoclinics, than the one of the minus equiabspotentials with that of the minus isapoclinics.* In other words, in the Indian and Pacific Oceans another disturbing factor seems to come into play. I reached the same conclusion when investigating the secular motion of a free magnetic needle.† I found, namely, that the secular magnetic wave travels in the main westward, but in eastern Asia, in the Pacific Ocean and on the western coast of America we have evidences of a wave, seemingly of a smaller amplitude, that travels *eastward*. We are thus succeeding in gradually drawing the lines closer and closer around the disturbing factors of terrestrial magnetism. And this is very important since theory cannot determine the deflecting centers for us; observation must point them out to us.

The next thing to which I wish to draw attention is the question at the head of this paper—*what is the secular motion of the secondary magnetic poles?* By comparing both diagrams it will be seen that beyond a doubt *the whole secondary magnetic system has been moving along the equator westwardly from 1780 to 1885.*

To make this clearer the following figures‡ are given:

	Position in 1780.		1829.		1885.	
	Lat.	Long. fr. Gr.	Lat.	Long. fr. Gr.	Lat.	Long. fr. Gr.
Secondary magnetic north pole	10° S.	30° W.§	10° S.	40° W.	20° S.	45° W.
" " south "	10 N.	65 E.	0	50 E.	5 S.	40° E.
" " equator	0	21 E.	0	7 E.	0	9 W.
cuts the geographical "	0	252 ? E.	0	187 E.	0	191 E.

The assignment of the positions of the poles is liable to an uncertainty of about 5° in latitude and in longitude. It is especially interesting to include in the comparison the results for 1829 as they have been derived from Erman and Petersen's figures based upon the Gaussian potential theory of terrestrial magnetism.‖

* See footnote to No. II, p. 200.

† See "Beitraege zur Kenntniss des Wesens der Saecular-Variation des Erdmagnetismus," p. 35, first footnote and p. 44.

‡ The results here given are slight improvements upon the quantities already published.

§ In the "abstract" published in Science, June 21, 1895, p. 675, this was erroneously given as 50° W. instead of 30° W.

‖ Erman and Petersen: Grundlagen der Gaussischen Theorie und die Erscheinungen des Erdmagnetismus im Jahre, 1829. Berlin, 1874. Table of computed inclinations.

It will be observed that both poles have undoubtedly been moving westwardly during the interval from 1780 to 1885. It would appear, moreover, as though they are not moving along the equator but along a line inclined to it, from the northern to the southern side. How much reliance is to be put upon this latter result I cannot, at present, say.

	Average Annual Motion 1780–1885. In Latitude.	In Longitude.
Secondary Mag'c N. P.....	0°·092	0°·146
" " S. P.....	0·146	0·242
Mean.....	0·119	0·194

These figures would appear to indicate that the two poles are moving westwardly and southwardly at different rates. Whether this is really the case must be the subject of a more detailed examination. It is sufficient to know, at this stage of our inquiry, the general direction and the average rate of motion.

Since the intersections of the agonic lines*—the lines marking out the places where the magnetic declination is zero—with the equator fall so nearly together with the secondary magnetic poles, it may be interesting to see how the agonic lines have been moving along the equator for the last $3\frac{1}{2}$ centuries. This opportunity is furnished by the table on the following page.

In the third and sixth columns are given the positions as obtained from charts giving the lines of equal magnetic declination. The fourth and seventh columns contain the computed quantities supposing the motion to have been linear. The formula, obtained by a least square adjustment of the observations properly weighted, is for the west agonic:

$$\lambda_w = +50°·6 + 0°·228\ (t - 1850)$$

for the east agonic,

$$\lambda_e = -83°·0 + 0°·139\ (t - 1850)$$

λ being the longitude and t the date to which λ refers.

By casting the eye over the differences between the observed and computed quantities, it will be noticed that the accord is satisfactory. Plotting the observed quantities, it will readily be seen that the motion for 350 years has been nearly linear for both agonics. A very slight curvature is noticeable in the secular motion of the west agonic. In the case of the east agonic, the errors of observation (or fluctuations) are so large as to mask any slight curvature that might be present.

We have before us a most interesting result. For $3\frac{1}{2}$ centuries the lines of no declination have been moving apparently

* Shown on the diagrams by the broken lines.

uniformly along the equator in a westward direction! *If* the motion continues at the same rate around the equator, then the west agonic will accomplish a complete revolution in $\cdot\frac{360}{228} = 1580$ years, the east agonic in $\cdot\frac{360}{139} = 2590$ years! The average annual motion of the two agonics is 0°·194, and the average period of revolution (if the agonics revolve around the equator) about 2000 years.

Longitudes of Intersections of Agonic Lines with the Equator.

Date.	Authority.	West Agonic.			East Agonic.		
		Obs'd.	Comp.	O.–C.	Obs'd.	Comp.	O.–C.
		°	°	°	°	°	°
1540	W. van Bemmelen*	−23†††	−20·1	−3	−100	−126·1	−26
1580	"	−17	−11·0	−6	---	−120·5	--
1600	"	− 8	− 6·4	−2	−116	−117·8	+ 2
1610	C. Hansteen†	−13	− 4·1	−9	−118	−116·4	− 2
1640	W. van Bemmelen*	− 2	+ 2·7	−5	−117	−112·2	− 5
1665	"	+ 9	+ 8·4	+1	−126	−108·7	−17
1680	"	+17·5	+11·8	+6	−112	−106·6	− 5
1700	E. Halley‡	+17·5	+16·4	+1	−118	−103·8	−14
1710	C. Hansteen†	+22·5	+18·7	+4	−119	−102·5	−16
1720	"	+26	+21·0	+5	---	−101·1	--
1730	"	+28	+23·2	+5	− 93	− 99·7	+ 7
1744	"	+31	+26·4	+5	−105‡‡‡	− 97·7	− 7
1756	"	+31	+29·2	+2	− 97‡‡‡	− 96·1	− 1
1770	"	+39	+32·4	+7	− 99‡‡‡	− 94·1	− 5
1780	"	+39	+34·6	+4	−100‡‡‡	− 92·7	− 7
1787	"	+40	+36·2	+4	−101‡‡‡	− 91·8	− 9
1800	"	+43	+39·2	+4	−100	− 90·0	−10
1817	T. Yeates‖	+42	+43·1	−1	− 77	− 87·6	+11
1827	A. Erman§	+53	+45·4	+8	− 75	− 86·2	+11
1829	Erman & Petersen¶	+50	+45·8	+4	− 74	− 85·9	+12
1833	P. Barlow**	+43·5	+46·7	−3	− 75	− 85·4	+10
1840	E. Sabine††	+49	+48·3	+1	−105	− 84·4	−21
1850	C. A. Schott‡‡	+49·5	+50.6	−1	---	− 83·0	--
1858	British Admiralty‖‖	+50·5	+52·4	−2	− 80	− 81·9	+ 2
1872	" " §§	+54	+55·6	−2	− 74·5	− 79·9	+ 5
1875	C. A. Schott‡‡	+52.5	+56·3	−4	---	− 79·5	--
1880	British Admiralty¶¶	+55	+57·4	−2	− 79·5	− 78·8	− 1
1885	G. Neumayer***	+54·2	+58·6	−4	− 80	− 78·1	− 2

* De Isogonen in de XVI^{de} en XVII^{de} Eeuw, Utrecht, 1893; values are preliminary, according to the author.

† Untersuchungen über den Magnetismus der Erde, Christiania, 1819, Atlas.

‡ Halley's Equal Variation Chart in Greenwich Observations for 1869, or in "Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus," No. 4, Hellmann, Berlin, 1894.

‖ Thomas Yeates' Equal Variation Chart for 1817; made use of copy in British Museum.

§ Erman's isogonic chart in Berghaus' Physikalischer Atlas, 1st edition, 1845.

¶ "Grundlagen der Gaussichen Theorie," etc., Berlin, 1874.

** Barlow's isogonic chart in Phil. Trans., 1833.

†† Sabine's isogonic chart, 1840; used copy in "Treatise upon Terrestrial Magnetism," London, 1871.

‡‡ Bulletin No. 6, U. S. Coast and Geodetic Survey.

‖‖ Used reduced copy in Neumayer's Atlas des Erdmagnetismus, Gotha, 1891.

§§ Used reduced copies in Admiralty Manual for Deviations of the Compass, German edition, Vienna, 1873, and London edition, 1874.

¶¶ Isogonic chart in Report of Challenger Expedition, Vol. II. Combined the result from this chart with that from Neumayer's chart for 1880.

*** Neumayer's Atlas des Erdmagnetismus.

††† East longitude, minus; west longitude, plus.

‡‡‡ Mean of several intersections.

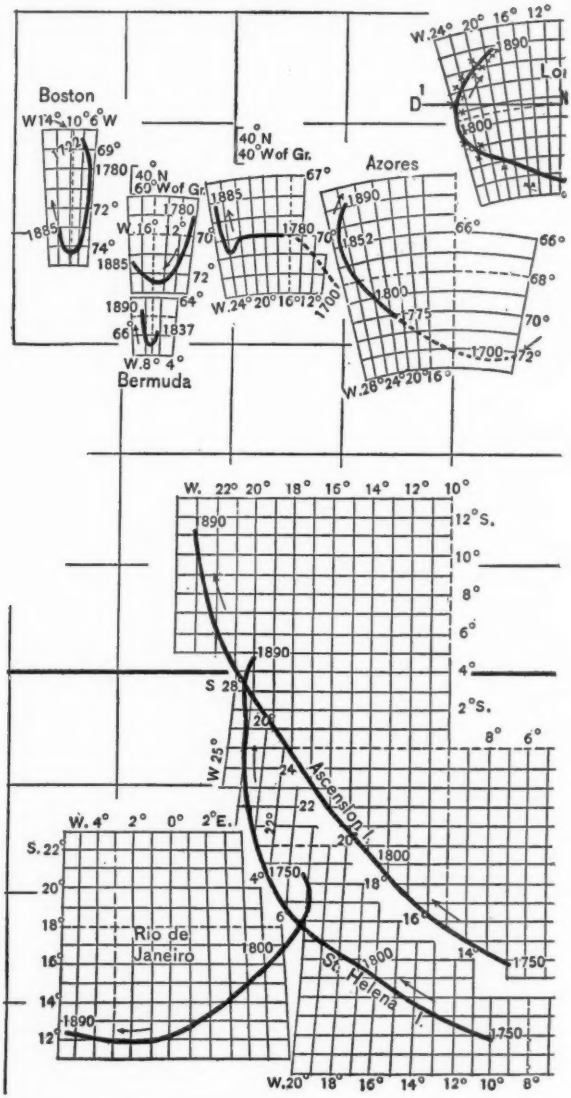
These results show how useless it is to endeavor to determine the secular variation period from the supposed motion of the agonic lines around the earth, as some eminent investigators have done. Not only will the result depend upon the particular agonic considered, but also upon the parallel of latitude along which the motion is supposed to take place. We are seemingly forced again to a conclusion which I have already formulated, viz., that we have no evidence as yet that the earth possesses a common secular variation period, it being questionable whether there really is a period at the close of which the same path will be traversed by a free magnetic needle. If the earth does possess a common period, then the curves at present being described at various stations are but branches or loops of the complete curve. If this period is as long as 2000 years, as above indicated, abundant opportunity is furnished for regarding the partial periods at the various stations as submultiples of the total period.

It should be noted that the period of 2000 years deduced from the average motion of the agonics is identical with that which we obtain if we suppose that the secondary magnetic system revolves around the equator at the average rate of the two secondary poles, viz: $\frac{360}{0.194} = 1860$ years. That is, the average annual westwardly motion in longitude along the equator is about the same (nearly 0°·2) for the secondary magnetic poles and the agonics.

I am inclined to think that the differences in the annual rate of motion as exhibited by the two secondary poles and, likewise, by the two agonics is real—parts of the same magnetic system may move with different velocities, the rate of motion of the particular part being governed by the portion of the earth over which it is passing. We must then be careful not to suppose that because a certain phase has traversed a section of the earth in a certain time, its rate of motion will continue the same over another section. In this way there arises a warping, a distortion or overlapping of our magnetic system.

A number of illustrations could be given as to how we can read the broad facts of the secular variation from the positions and the motions of the secondary magnetic poles. I shall give only two, however, in the present number.

First. *Where should we expect the largest and the smallest secular change in declination during the interval 1780–1885?* The largest change in declination would be expected where the change in the horizontal component of the secondary system is a maximum, i. e., in the region traversed by that branch of the secondary magnetic equator corresponding to the shorter distance in longitude of the secondary poles, hence over the eastern Atlantic and adjacent countries.



The least change in declination would be encountered where the horizontal component of the secondary system would be least affected by the motion of the poles, i. e., in the region traversed by the other branch of the secondary magnetic equator, viz., the western Pacific Ocean.

Both deductions are amply borne out by observations and are prettily illustrated by a chart, as yet unpublished, to which I have made allusion several times, viz., the chart showing graphically the secular variation in declination for points on the earth distant 20° in latitude and in longitude.

As a second illustration of the importance of study of the secondary magnetic poles, I shall reproduce a few of the secular motion curves given in previous papers, and endeavor to explain a phenomenon which was a source of perplexity to me when I first observed it.

On the diagram* opposite we have given the curves that have been described in the course of time by a magnetic needle freely suspended. It will be noticed that while the direction of motion is clockwise throughout there is a marked difference between some of the curves, as for example, between those of Ascension and St. Helena Islands and that of Rio de Janeiro. It would appear as though the latter curve has swung itself around. The same thing is exhibited by the curve for station 40° N. and 60° W. and by the curves west thereof. West of this station, the curves for the interval drawn follow the American type; east, the European. It is evident that some important change in magnetic distribution must have occurred in the interval 1750–1890 in the region between the stations exhibiting the contrasted motions.

Upon looking into this matter I find that the secondary north end attracting pole during the stated interval moved between Ascension Island and Rio de Janeiro—away from Ascension Island and towards the latter station. Hence, it follows that the dip of the north end of the needle at Ascension Island decreased, or that of the south end *increased*, while on the other hand, the northerly dip at Rio de Janeiro increased or that of the southerly *decreased*. At Ascension Island and stations east (up to a certain line), the southerly dip increased; at Rio de Janeiro and west (up to a certain line), it decreased.

This is precisely the state of affairs exhibited by the curves, as will be seen by inspection.

For the better understanding of the foregoing the following geographical positions are given:

	Latitude.	Longitude.
St. Helena Is.	15° 55′ S.	5° 44′ W.
Ascension Is.	7 56 S.	14 23 W.
Rio de Janeiro	22 55 S.	43 10 W.

From the table on p. 318 we find that the position of the secondary north pole was:

in 1780	10° S. 30° W.
in 1885	20 S. 45 W.

* Taken from the Physical Review, vol. iii, No. 13, Plate I.

In 1780 it was consequently west of St. Helena and Ascension Islands but east of Rio de Janeiro. In 1750 it was still west of the first two stations though now nearer them, as is apparent from the secular variation curves—the increasing southerly inclination still prevailing in 1750. In 1885 it appears to have been close to Rio de Janeiro, and we ought to expect about this date the maximum northerly or minimum southerly dip to occur. As a matter of fact, this turning point was reached in about 1882 (see curve).* The southerly dip is at present increasing, i. e., the secondary north end attracting pole will be found at the present time *west* of Rio de Janeiro.

Similar considerations will explain to us the change in magnetic declination at these three tropical stations.

Enough has been given to show how exceedingly helpful the secondary magnetic poles may be to us in the study of the phenomena of the distribution and of the secular variation of geomagnetism.

By watching the progressive westward motion of the secondary south end attracting pole, which was in 1885 in about 5° south latitude and 40° east longitude we may be able to predict the coming of the phase of minimum northerly inclination which is at the present time setting in in central Europe and marching westwardly.

It may be of interest and of value to give the dates at which the branch of the secondary magnetic equator corresponding to the shorter difference in longitude of the secondary poles passed through various stations along the line of westward march. The figures were obtained with the aid of the relation

$$\triangle I = 0 = I_{obs'd} - 2 \tan \varphi \text{ or } I_{obs'd} = I_{comp'd} = 2 \tan \varphi.$$

Station.	Latitude.	Longitude.	Date of Passage of Sec. Mag'c Eq.
	° ′	° ′	
Berlin	52 32 N.	13 23 E.	1820
Rome	41 53	12 26	1830
Basle	47 34	7 36	1839
Geneva	46 12	6 09	1845
Paris	48 50	2 20 E.	1858
London	51 30	0 07 W.	1862
Equator	0 0	21 E.	1780
"	0 0	7 E.	1829
"	0 0	2 E.	1840
"	0 0	9 W.	1885
Capetown	33 56	18 29 E.	1844
St. Helena Island	15 55 S.	5 44 W.	1890
Ascension "	7 56	14 23 W.	1905 (?)
Rio de Janeiro	22 55	43 10 W.	----

* Deduced by me in Beitraege zur Kenntniss des Wesens der Sac. Var'n, p. 36, before the presence of secondary poles had been recognized.

In conclusion a few words must be said with regard to the results obtained thus far. We have found that by resolving the observed magnetic field into two, one polar and symmetrical about the rotation axis, the other the residual field, that this latter is apparently directed approximately equatorially. It has been amply demonstrated, I believe, that this mode of resolution is a very convenient and promising one for the study of the complex phenomena of the distribution and the secular variation. This breaking up of the total field into two has thus far been wholly arbitrary, however. To assert the actual existence of the secondary equatorial field we must endeavor to deduce it theoretically in some manner. We must show that there is some cause for such a polarization. For example, suppose we have given the primary polar field, which in fact we know to exist, though in a more complex form, can we deduce from the motions of the earth a secondary equatorial polarization as the result of self-induction? If so, what conditions of the physical constitution of the earth must we presuppose in order to get such an unsymmetrical equatorial polarization as our residual field reveals? That is, why are the secondary magnetic dip poles but 90° different in longitude?* It is evident that the solution of this question is likely to throw some light upon the secrets hidden in the bowels of the earth. It will be interesting to see whether we shall reach the same result obtained by Prof. Bigelow in a totally different manner, viz., that the earth is a magnetic shell of the thickness of about 790 miles.†

Finally, can the secular variation be explained by the reflex action of the secondary field upon the primary? This is the nature of the questions that will serve as the subject of a systematic examination in subsequent numbers.

Chicago, Aug. 15, 1895.

* The two foci obtained by constructing "the isanomalous lines of geomagnetic potential" are according to Prof W. von Bezold about 180° apart in longitude. See foot-note page 200, of previous number.

† F. H. Bigelow: The Earth a Magnetic Shell, this Journal, Art. VIII, August, 1895.

ART. XXXVI.—*Studies in the Electro-magnetic Theory.—I. The law of electro-magnetic flux;** by M. I. PUPIN, Ph.D., Columbia College, New York.

THE law of electro-magnetic flux is a short expression for the well-known quantitative relations between electromotive force and electric flux on the one hand and magnetomotive force and magnetic flux on the other. Ohm's law is a part of it.

These relations are statements of experimental facts which we know to hold true for constant and slowly varying forces. The object of this investigation is to show the exact position which this law occupies in Maxwell's electro-magnetic theory; to point out its limitations; to show that Maxwell's electro-magnetic theory of light demands a more general form of this law; and finally, to present a general form of this law of which both its ordinary form and also those forms which were assumed hypothetically in some of the recent developments of the electro-magnetic theory of light are special cases.

1. *The two fundamental laws of Maxwell's Electro-dynamics.*

A brief statement of Maxwell's electro-magnetic theory seems desirable in this discussion. For the sake of brevity none but its most essential features will be presented, and that in such a way as to emphasize as forcibly as possible the essential differences between this theory and the older electro-magnetic theories.

The essential features of the Maxwellian theory are reducible to two, which may be called its two characteristic features. These two characteristic features can be exhibited in a very simple manner by considering the gradual change in form and in meaning which the following two well known experimental laws, relating to magneto-electric and to electro-magnetic induction, undergo as we pass from the views of old electric theories to those of the Maxwellian theory. These laws I choose to state in the following form for reasons which will be evident presently:—

First law:—A varying magnetic field induces a field of electric force in all electric conductors within its region. The electromotive force around any simple circuit† of this induced

* Read in abstract before the Am. Assoc. Adv. Science at its Springfield meeting, Aug. 30, 1895.

† The expression *simple circuit* needs an explanation. Consider any point of the field. Pass a plane through it and in this plane draw an infinitely small area around the point under consideration. If the boundary of this elementary area be such that none of its points contain more than one branch of the boundary curve, then this boundary curve is a simple circuit around this point.

electric field is proportional to the rate of variation of the magnetic flux through any surface bounded by this circuit.

Second law:—An electric current induces a field of magnetic force . . . . . .
The magnetomotive force around any simple circuit of this induced magnetic field is proportional to the current passing through any surface bounded by this circuit.

For the sake of brevity the factors of proportionality are not explicitly mentioned. It is well to observe, however, that they are numerical and that by a suitable selection of electric units they could be made unity in each case.

There is evidently a considerable formal resemblance between these two experimental laws when they are stated in the form in which they have just been stated. This formal resemblance can be carried considerably further without departing from the views of pre-Maxwellian electric theories. All that is needed is a simple adjustment of the electric terminology of the pre-Maxwellian period. This is the step which is now in order. It leads along the shortest path from old theories to Maxwell's electro-magnetic theory.

Consider two electric conductors A and B, insulated from each other, one charged with a certain quantity of positive electricity and the other with an equal charge of negative electricity. Consider now a surface surrounding any one of these two conductors. The total electric flux through this surface is numerically equal to the total quantity of electricity enclosed by the surface. Hence it is also equal to the total *integral electric current* which would be obtained if the total positive charge were carried across this surface to the negatively charged conductor and thus the two conductors reduced to their neutral state. We can speak, therefore, of a total electric flux across a surface as of a *fictitious integral current* through this surface. We can speak of it also as of a *total electric displacement* in the sense that if the two conductors are neutral and a certain quantity of positive or negative electrification is transferred from one to the other and therefore displaced from one side of the bounding surface to the other we shall have a total electric flux across this surface numerically equal to the total electric displacement across the same surface. With this mental reservation, namely, that we are using certain terms in their figurative sense only, we can always employ the expressions "*total electric flux*," "*total integral current*," and "*total electric displacement*" as synonymous terms without departing from the views of pre-Maxwellian theories.

So far we have not restricted the fictitious total integral current or displacement to any particular paths. That shall be done now.

Let these paths be such that at any moment the total fictitious electric transference through any elementary area up to that moment is equal to the electric flux through that area at that moment. Then, as long as we remember that we are speaking of a *fictitious "integral current"* and a *fictitious "electric displacement"* through any elementary area in an electric field, we can employ these two terms as synonymous with "electric flux" through that area without departing from the views of the pre-Maxwellian period.

Again just as the electric current through any elementary area of a conductor is defined as the rate of variation of the integral current, so we can also speak of a current through the dielectric without deserting the views of old electro-magnetic theories provided that we take it as granted that this dielectric current is fictitious, since it is the rate of variation of a fictitious integral current. The expression "*dielectric or displacement current*" becomes, therefore, synonymous with rate of variation of the electric flux. Similarly we can substitute the expression *magnetic current* for the expression "*rate of variation of magnetic flux.*"

To distinguish the real, that is the electric conduction current, from the fictitious or displacement current, the expression "*conduction current*" must be used when the real and not the fictitious (displacement) current is meant.

This precaution is unnecessary in the case of the magnetic current, since there is no magnetic conduction current.

The laws of magneto-electric and of electro-magnetic induction can now be stated more symmetrically, as follows:—

First law:—A region of magnetic . . . . . currents induces a field of electric force *in all electric conductors within that region.* The electromotive force around any simple circuit in this induced electric field is proportional to the magnetic . . . . . current passing through any area which is bounded by this circuit.

Second law:—A region of electric *conduction* currents induces a field of magnetic force . . . . . The magnetomotive force around any simple circuit in this induced magnetic field is proportional to the electric *conduction* current passing through any area which is bounded by this circuit.

The formal resemblance between the two laws is very striking now. It would be perfect if we either omitted the words which are in italics or filled out suitably the dotted lacunæ.

The last alternative is not admissible, because we know nothing about magnetic conduction currents, nor about magnetic conductors. The first alternative does not strike one so unfavorably. There is really no evidence against the permissibility of omitting the words in italics from the statement of the

first law. It is true that Faraday's experiments, by which he discovered that law, prove the existence of no other induced electromotive forces excepting those which Faraday detected in conductors. But these experiments neither affirm nor do they deny the presence of magneto-electric induction in dielectrics. On the other hand, Faraday's experiments on dielectric and diamagnetic substances and his speculative views of electro-magnetic phenomena urge us with an irresistible force to the belief that electromotive forces just like magnetomotive forces are induced around every circuit, no matter whether that circuit pass through a conductor or through a dielectric (including the most perfect of all dielectrics, that is a perfect vacuum), and that just as the magnetic displacement current is real in the sense that it produces inductive effects, so the electric displacement current is not a fiction, as one who is faithful to the views of older electric theories has to assume, but it is just as real as the electric conduction current in the sense that it is an actually existing process in the dielectric, which is just as capable of inducing magnetomotive forces as the conduction current. The mechanism of this process is, of course, just as unknown to us as the mechanism of that process which is called the electric conduction current. Maxwell was the first to feel the force of this tendency of Faraday's experiments and speculations and to yield to it, making thus a radical departure from the views of old electric theories. His statement of the two laws of induction omits, therefore, the words which are in italics in the last statement of these laws. Hence the following wording of these two laws is in accordance with Maxwell's views:—

First law:—*Every magnetic current induces a field of electric force. The electromotive force around any simple circuit in this induced electric field is proportional to the magnetic current passing through any area which is bounded by this circuit.*

Second law:—*Every electric current induces a field of magnetic force. The magnetomotive force around any simple circuit in this induced magnetic field is proportional to the electric current passing through any area which is bounded by this circuit.*

In this generalized form these two laws form the foundation of Maxwell's electro-magnetic theory.* This theory may, therefore, be described broadly as that theory which generalizes the two experimental laws of magneto-electric and of electro-magnetic induction by extending the region of magneto-electric induction and of the electric current from conductors to the dielectric.

* See O. Heaviside, Phil. Mag., February, 1888; H. Hertz, Wied. Ann., xxiii, p. 84, 1884; xl, p. 577, 1890.

So far an electro-magnetic field of invariable geometrical configuration has been considered. It should be observed now that the two laws suffice to describe completely the inductive effects in an electro-magnetic field of variable geometrical configuration also. A field of variable geometrical configuration means, of course, a field in which the various *sources of flux* (like electrically or magnetically charged bodies and conductors carrying electric currents) are in relative motion with respect to bodies which are under the inductive action of these sources. According to these laws the inductive effects in any circuit depend on the rate of variation of the flux through that circuit and on nothing else; they are, therefore, independent of the particular method by which that variation is produced; whether by varying the intensity of the field; or by motion of the various parts of the field; or by keeping everything constant and moving the circuit under consideration, it is immaterial. This is simply an extension of the experimental fact that the electromotive force induced in a conducting circuit follows the same law whether that electromotive force be induced by the motion of the circuit towards a magnet or by the motion of the magnet towards the circuit, or by keeping the two in fixed relative position and varying the strength of the magnet.

The fundamental quantities in this theory are electric current and electromotive force on the one hand and magnetic current and magnetomotive force on the other. Calling them the *fundamental vectors of the electro-magnetic field*, we can say that the *first characteristic feature of Maxwell's electro-magnetic theory consists in the perfectly symmetrical form of cross-connection between its fundamental vectors, one of these cross-connections stating the law of induced magnetomotive force and the other stating the law of induced electromotive force.*

A symbolical statement of these two laws shows this symmetry more clearly.

Let X, Y, Z be the components of the induced electromotive intensity at any point of the field.

Let α, β, γ be the components of the induced magnetomotive intensity at same point of the field.

Let $\frac{df}{dt}, \frac{dg}{dt}, \frac{dh}{dt}, \frac{da}{dt}, \frac{db}{dt}, \frac{dc}{dt}$ be the components of the intensity of the electric and magnetic currents, respectively, at the same point.

If the electric vectors be measured in electrostatic and the magnetic vectors be measured in electro-magnetic units, then, V being the ratio between the two, we can state symbolically the two laws as follows:

$$\left.\begin{aligned}\frac{4\pi}{V}\frac{da}{dt} &= -\left(\frac{\delta Z}{\delta y} - \frac{\delta Y}{\delta z}\right)\\ \frac{4\pi}{V}\frac{db}{dt} &= -\left(\frac{\delta X}{\delta z} - \frac{\delta Z}{\delta x}\right)\\ \frac{4\pi}{V}\frac{dc}{dt} &= -\left(\frac{\delta Y}{\delta x} - \frac{\delta X}{\delta y}\right)\end{aligned}\right\}\ \text{First law.}$$

$$\left.\begin{aligned}\frac{4\pi}{V}\frac{df}{dt} &= \frac{\delta\gamma}{\delta y} - \frac{\delta\beta}{\delta z}\\ \frac{4\pi}{V}\frac{dg}{dt} &= \frac{\delta\alpha}{\delta z} - \frac{\delta\gamma}{\delta x}\\ \frac{4\pi}{V}\frac{dh}{dt} &= \frac{\delta\beta}{\delta x} - \frac{\delta\alpha}{\delta y}\end{aligned}\right\}\ \text{Second Law.}$$

An immediate consequence of these two laws is the following important relation:—

$$\frac{\delta}{\delta x}\left(\frac{da}{dt}\right) + \frac{\delta}{\delta y}\left(\frac{db}{dt}\right) + \frac{\delta}{\delta z}\left(\frac{dc}{dt}\right) = 0$$

$$\frac{\delta}{\delta x}\left(\frac{df}{dt}\right) + \frac{\delta}{\delta y}\left(\frac{dg}{dt}\right) + \frac{\delta}{\delta z}\left(\frac{dh}{dt}\right) = 0.$$

That is to say, the magnetic and the electric currents follow the laws of flow of an incompressible fluid. Hence they form closed paths. This is one of the essential differences between the Maxwellian theory and the older electro-magnetic theories. Numerous other essential differences can be deduced directly from the two laws by a proper interpretation of the physical meaning of the perfect formal similarity existing between them. One or two only of the several of these essential differences which were first pointed out clearly by Hertz,* should be mentioned here, in order to show their general character. The magnetic field induced by a loop of wire carrying an electric current (which we may call a varying electric solenoid) has the same form as the electric field induced by a varying magnetic solenoid which has the same geometrical configuration as the loop; hence just as two varying electric solenoids exert a magnetic force, so two varying magnetic solenoids exert an electric force upon each other.

An experimental proof of the existence of the electric field of force induced by a varying magnetic solenoid would constitute a *direct experimental evidence* in favor of the Maxwellian theory. It is evident, however, that extremely serious and apparently insurmountable technical difficulties would be encountered by every attempt to verify experimentally this relation and similar other reciprocal relations which, taken

* Wied. Ann. xxiii, p. 84, 1884.

together, constitute the physical meaning of the perfect similarity in form between the two fundamental laws of Maxwell's electro-magnetic theory.* Rowland's classical experiment which proved the existence of a magnetic field produced by a moving electrostatic charge, and Röntgen's detection of the magnetic effect of a varying dielectric polarization, may be considered as the only direct experimental evidences ever obtained.

2. *Second part of Maxwell's theory.*

A search for a source of indirect experimental evidences leads to the second and most interesting, but at the same time most difficult, part of Maxwell's electro-magnetic theory. *The principal feature of this part is the second characteristic feature of this theory. It is the importance of the function which is performed by the physical constants of the field, namely, by the specific inductive capacity, the magnetic permeability, and the resistivity.*

These constants Maxwell defines by the law of flux, which in the well known notation is expressed as follows:

$$\left.\begin{aligned} f &= \frac{K}{4\pi} X,\ g = \frac{K}{4\pi} Y,\ h = \frac{K}{4\pi} Z \\ a &= \frac{\mu}{4\pi} \alpha,\ b = \frac{\mu}{4\pi} \beta,\ c = \frac{\mu}{4\pi} \gamma \\ u &= \frac{X}{k},\ v = \frac{Y}{k},\ w = \frac{Z}{k} \end{aligned}\right\} \text{for isotropic media.}$$

$$\left.\begin{aligned} f &= \frac{K_1}{4\pi} X,\ g = \frac{K_2}{4\pi} Y,\ h = \frac{K_3}{4\pi} Z \\ &\cdots\cdots\cdots\cdots \\ u &= \frac{X}{k_1},\ v = \frac{Y}{k_2},\ w = \frac{Z}{k_3} \end{aligned}\right\} \text{for anisotropic media.}$$

It should be observed now that the first part of this law, referring to isotropic media, is a statement of experimental facts as long as we confine ourselves to constant and slowly-varying forces; it is an hypothesis† in every other case. The second part, referring to anisotropic media, was a pure hypothesis at the time when Maxwell first stated it. He justified it by pointing out the close connection between the optical and the electro-magnetic constants. Hence just as double refraction of light in a substance proves that the optical constants of the substance are different in different directions, so the double refraction of

* Lodge, Phil. Mag., June, 1889.

† See Goldhammer, Wied. Ann. xlvi, p. 99, 1892.

electro-magnetic waves in a substance can be accounted for by the electro-magnetic theory by assuming that the electro-magnetic constants of the substance are different in different directions. There seems to be no strong evidence against the assumption that Maxwell looked upon this form of the law of flux as merely a first approximation to truth.

We are ready now to describe the sources of indirect experimental evidences in favor of the hypotheses on which rest the two fundamental laws of Maxwell's electro-dynamics. It seems desirable, however, to make first the following slight digression. Combining the two fundamental laws with the law of flux and considering, for the sake of brevity, that the medium is isotropic and non-absorptive, we obtain:

$$\left.\begin{array}{l} \dfrac{\mathrm{K}}{\mathrm{V}}\dfrac{dX}{dt} = \dfrac{\delta\gamma}{\delta y} - \dfrac{\delta\beta}{\delta z} \\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \end{array}\right\} \text{(A)}$$

$$\left.\begin{array}{l} \dfrac{\mu}{\mathrm{V}}\dfrac{\delta\alpha}{dt} = -\left(\dfrac{\delta \mathrm{Z}}{\delta y} - \dfrac{\delta \mathrm{Y}}{\delta z}\right) \\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \end{array}\right\} \text{(B).}$$

Equations (A) and (B) and similar equations for absorptive and anisotropic media are very often called the mathematical statement of the two fundamental laws of Maxwell's electro-dynamics. Such a presentation of the Maxwellian theory seems not only entirely unnecessary but also misleading. For the hypotheses by means of which Maxwell passed from the two experimental laws of magneto-electric and of electro-magnetic induction to the two fundamental laws of his electro-dynamics have very little if anything to do with what may or may not be the complete form of the law of flux as stated above, not even if we choose to accept Maxwell's mechanical models of the electro-magnetic field as correct representations of what is going on in such a field. In these models the constants K, μ, k, have a definite mechanical meaning, but this meaning does by no means lead to the conclusion that for all periodicities of the impressed forces equations (A) and (B) are equivalent to that mathematical statement of the two fundamental laws in which the current and the forces appear as fundamental vectors, and no reference whatever is made to the physical constants of the field. Equations (A) and (B) should, therefore, be treated as an adulteration of Maxwell's fundamental laws, the foreign element in this adulteration being that form of the law of flux which Maxwell employed. This adulteration may do, and as

will be pointed out presently, actually does just as well, in many instances, as the real thing, but there are considerations, to be discussed presently, which seem to speak very forcibly against the equivalence between this adulteration and the real thing.

The main thread of the discussion can now be taken up again. Combining the two fundamental laws with the law of flux, the well known relations of which the following are types are easily obtained:

$$\frac{d^2X}{dt^2} + \frac{4\pi}{k_1K_1}\frac{dX}{dt} = \frac{V^2}{\mu K_1}\Delta^2X$$
. . . . . .
. . . . . .
$$\frac{d^2\alpha}{dt^2} + \frac{4\pi}{k_1K_1}\frac{d\alpha}{dt} = \frac{V^2}{\mu K_1}\Delta^2\alpha$$
. . . . . .
. . . . . .

For all non-absorptive isotropic insulators we shall have

$$\frac{d^2X}{dt^2} = \frac{V^2}{K}\Delta^2X$$
. . . . . .
$$\frac{d^2\alpha}{dt^2} = \frac{V^2}{K}\Delta^2\alpha$$
. . . . . .

These equations describe the source of indirect experimental evidences of the Maxwellian theory. They constitute the second part of this theory, and they show better than any words can the important function which the physical constants of the field perform in our modern views of electro-magnetic phenomena. It was reserved for Hertz and his followers to reveal by actual experiment the wealth of this source and to demonstrate beyond all reasonable doubt that long electro-magnetic waves are propagated in perfect accordance with the laws stated in these equations. These laws are, within certain limits which will be mentioned presently, a perfect analogy to the laws of propagation of luminous waves. Hence experimental results obtained from electro-magnetic phenomena involving the operation of forces whose period is not shorter than the shortest period of the Hertzian waves, give a decisive victory for the hypotheses which underlie the Maxwellian electro-magnetic theory.

But this theory is much broader. It states that, probably, light is an electro-magnetic phenomenon. It fails, however, to give a satisfactory account of some of the most striking optical

phenomena, as, for instance, dispersion, absorption, rotation of the plane of polarization, etc. In other words, it fails to give a satisfactory general relation between optical and electro-magnetic constants without resorting to additional hypotheses.

This failure is not confined to the electro-magnetic theory; all optical theories labor under the same difficulty. There is, however, one distinct and important advantage which the electro-magnetic theory has over other optical theories. It is the definiteness of its premises. For whereas the dynamical theories of light must start with the material attributes, density and elasticity, of an unknown substance, the ether, which possibly may not resemble ordinary matter and whose material attributes, if it has them at all, seem to be entirely outside of the possibility of direct experimental test, the electro-magnetic theory endows the same substance with no other attributes excepting those contained in Maxwell's first and second law of electro-dynamics and the law of flux, and it proves the actual existence of these attributes by direct experiment covering a large region of electro-magnetic phenomena, the region of the Hertzian waves. It is, therefore, perfectly sure of its ground in one extensive region of ether manifestations.

The limitations of the Maxwellian hypotheses are also very clear from the character of the experiments which guided the formation of these hypotheses. These experiments were performed with constant or very slowly-varying forces, hence the obvious probability that Maxwell's hypotheses need a modification in the case of electro-magnetic phenomena involving the operation of rapidly-varying forces; in other words, Maxwell's electro-magnetic theory must be extended so as to include the periodicity of its fundamental vectors before it can become a satisfactory optical theory.

The first and the second law of Maxwell's electro-dynamics in the form stated above contain no mention of the physical constants of the field. If our experience with optical phenomena can be relied upon to guide us in our attempt to extend the electro-magnetic theory, then we should naturally infer that the element of periodicity can enter into Maxwell's electro-magnetic theory through the physical constants, only, of the field, and therefore through the law of flux and not through the two fundamental laws, which, in my opinion, do not contain these constants explicitly. It is, therefore, the law of flux which in all probability must be extended so as to include the periodicity of the impressed forces, if Maxwell's electro-magnetic theory is to become a theory of light. A careful analysis of the several satisfactory electro-magnetic theories of dispersion and absorption and of the magnetic rotation of the plane of polarization supports this conclusion. I

refer in particular to the following investigations and reserve a more detailed discussion of this matter for a future occasion:

Von Helmholtz, Wied. Ann. xlviii, pp. 389 and 723, 1893. Goldhammer, Wied. Ann. xlvii, pp. 93 and 265; xlvi, p. 71, 1892. Drude, Wied. Ann. xlvi, p. 353, 1892; xlviii, p. 122 and p. 356; xlix, p. 960, 1893. Ebert, Wied. Ann. xlviii, p. 1, 1893; li, p. 268, 1894.

3. *Extension of the law of flux.*

The question arises now, can we without resorting to any hypotheses not already contained in Maxwell's electro-magnetic theory find a more general and satisfactory form for the law of flux? This question can be answered in the affirmative, provided that by a law of flux we mean a quantitative relation between the electric force and the electric flux on the one hand and the magnetic force and magnetic flux on the other.

Consider two large conductors insulated from each other by a perfect non-conductor. Let one of them be connected to one pole of a galvanic cell and the other to the other pole. We know that as soon as these conductors are connected in the manner described an integral transient current takes place whose value depends on the capacity of the conductors. The work of the cell appears half as heat in the conducting parts and half as potential energy in the dielectric. If Q be the integral current and E the electromotive force of the cell, then

$$EQ = \text{total work of the cell.}$$
$$\tfrac{1}{2}EQ = \text{potential energy stored in the dielectric.}$$

Let X, Y, Z be the components of the intensity of the electromotive reaction at any point of the dielectric and at any moment during the flow of the integral current.

Let $\frac{df}{dt}, \frac{dg}{dt}, \frac{dh}{dt}$ be the components of the intensity of the electric displacement current at the same point and time, then

$$\int_0^t dt \int \left(X\frac{df}{dt} + Y\frac{dg}{dt} + Z\frac{dh}{dt} \right) d\tau = \tfrac{1}{2}EQ$$

where $d\tau$ is an elementary volume of the dielectric. The integration extends over the whole dielectric field and over the interval of time from the start to the completion of the integral current. It is evidently immaterial how X . . . . and f . . . . vary during the flow of the integral current; the final resultant potential energy in the dielectric is, according to experiment, always the same and equal to $\frac{1}{2}EQ$. According to their physical character X . . . f . . . are, of course, finite, continuous, and singly-valued functions of the time; we can apply, therefore, to the indicated integration all the rules of calculus which

are applicable to such functions. Integrating by parts we obtain

$$\int(\mathrm{X}_1 f_1+\mathrm{Y}_1 g_1+\mathrm{Z}_1 h_1)d\tau-\int_0^t dt\int\left[f\frac{d\mathrm{X}}{dt}+g\frac{d\mathrm{Y}}{dt}+h\frac{d\mathrm{Z}}{dt}\right]d\tau=\tfrac{1}{2}\mathrm{EQ}$$

where the suffix 1 denotes that the value at the moment of cessation of the integral current is to be taken.

Now it can be easily shown that the first integral equals EQ. Hence

$$\int_0^t dt\int\left\{\left(\mathrm{X}\frac{df}{dt}-f\frac{d\mathrm{X}}{dt}\right)+\left(\mathrm{Y}\frac{dg}{dt}-g\frac{d\mathrm{Y}}{dt}\right)+\left(\mathrm{Z}\frac{dh}{dt}-h\frac{d\mathrm{Z}}{dt}\right)\right\}d\tau=0$$

Every functional relation between $\mathrm{X}\ldots f\ldots$ which will satisfy this equation will be a permissible form of the law of flux.

For instance,

$$f=\frac{\mathrm{K}}{4\pi}\mathrm{X},\ g=\frac{\mathrm{K}}{4\pi}\mathrm{Y},\ h=\frac{\mathrm{K}}{4\pi}\mathrm{Z}$$

is one set of relations which will satisfy this equation.

Here is another set

$$f=\frac{1}{4\pi}(\mathrm{K}_{11}\mathrm{X}+\mathrm{K}_{12}\mathrm{Y}+\mathrm{K}_{13}\mathrm{Z})$$

$$g=\frac{1}{4\pi}(\mathrm{K}_{21}\mathrm{X}+\mathrm{K}_{22}\mathrm{Y}+\mathrm{K}_{23}\mathrm{Z})$$

$$h=\frac{1}{4\pi}(\mathrm{K}_{31}\mathrm{X}+\mathrm{K}_{32}\mathrm{Y}+\mathrm{K}_{33}\mathrm{Z})$$

where $\mathrm{K}_{12}=\mathrm{K}_{21},\ \mathrm{K}_{13}=\mathrm{K}_{31},\ \mathrm{K}_{23}=\mathrm{K}_{32}$

By a suitable selection of coördinate axes this set can be written

$$f=\frac{\mathrm{K}_1}{4\pi}\mathrm{X}$$

$$g=\frac{\mathrm{K}_2}{4\pi}\mathrm{Y}$$

$$h=\frac{\mathrm{K}_3}{4\pi}\mathrm{Z}$$

A third set of relations is obtainable by supposing f, g, h to vary harmonically, since in this case

$$\frac{d^{2n}f}{dt^{2n}}=(-1)^n p^{2n}f,\ \text{etc.}$$

where $p = 2\pi\times$ frequency, we obtain

$$f=\left(\frac{4\pi}{\frac{4\pi}{K_1}-p^2A}\right)X$$

$$g=\left(\frac{4\pi}{\frac{4\pi}{K_2}-p^2B}\right)Y$$

$$h=\left(\frac{4\pi}{\frac{4\pi}{K_3}-p^2C}\right)Z$$

as another possible set of relations.

Here
$$A=a_1-a_2p^2+a_4p^4-\ldots.$$
$$B=b_1-b_2p^2+b_4p^4-\ldots.$$
$$C=c_1-c_2p^2+c_4p^4-\ldots.$$

In this permissible form of the law of flux the constant which corresponds to specific inductive capacity is a function of the periodicity. A large variety of other relations can easily be found all of which will satisfy the integral equation.

If the dielectric is absorptive then the value of the integral does not vanish but equals the heat developed in the dielectric. Hence in general

$$(C)\int_0^t dt\int\left\{\left(X\frac{df}{dt}-f\frac{dX}{dt}\right)+\left(Y\frac{dg}{dt}-g\frac{dY}{dt}\right)+\left(Z\frac{dh}{dt}-h\frac{dZ}{dt}\right)\right\}d\tau\geq 0$$

contains all the possible forms of the law of flux relating to the electrical force and the electric flux, which are consistent with Maxwell's hypotheses and with the quadratic form of electropotential energy.

A similar relation between the magnetic force and the magnetic flux can be obtained. Consider a loop of wire in which a galvanic cell sets up a current. From the moment of closing the circuit up to the time when the current becomes constant magnetic energy is stored up in the medium. The final amount of magnetic energy will be in the well known notation

$$W=\tfrac{1}{2}LC^2$$

Let α, β, γ be the components of the intensity of the magnetomotive reaction at any point of the field and at any moment during the flow of the magnetic integral current.

Let $\frac{da}{dt}, \frac{db}{dt}, \frac{dc}{dt}$ be the components of the intensity of the magnetic current at the same point and the same moment, then

$$\int dt\int\left(\alpha\frac{da}{dt}+\beta\frac{db}{dt}+\gamma\frac{dc}{dt}\right)d\tau=\tfrac{1}{2}LC^2$$

Integrating by parts we obtain

$$\int(\alpha_1 a_1+\beta_1 b_1+\gamma_1 c_1)d\tau-\int_0^t dt\int\left(a\frac{d\alpha}{dt}+b\frac{d\beta}{dt}+c\frac{d\gamma}{dt}\right)d\tau=\tfrac{1}{2}\mathrm{LC}^2$$

The first integral refers to the state of the field when the electric current has become constant and therefore the magnetic integral current has ceased to flow. The value of this integral can be easily shown to be LC^2 and we have, therefore,

$$\int_0^t dt\int\left\{\left(\alpha\frac{da}{dt}-a\frac{d\alpha}{dt}\right)+\left(\beta\frac{db}{dt}-b\frac{d\beta}{dt}\right)+\left(\gamma\frac{dc}{dt}-c\frac{d\gamma}{dt}\right)\right\}d\tau=0$$

The same relations can be deduced from this integral as from (C). If the dielectric of the field is absorptive then the last integral equals the heat developed in the field. We can put, therefore

$$(\mathrm{D})\int_0^t dt\int\left\{\left(\alpha\frac{da}{dt}-a\frac{d\alpha}{dt}\right)+\left(\qquad\right)+\left(\qquad\right)\right\}d\tau\geqq 0$$

as the most general relation between the magnetic force and the magnetic flux.

Equations (C) and (D) are the consequence of the following premises:—First, the hypotheses by means of which we pass from the two experimental laws of electro-magnetic and magneto-electric induction to Maxwell's two fundamental laws are correct. Second, it is an experimental fact that the electric energy of the field is proportional to the square of the integral electric and the magnetic energy is proportional to the square of the integral magnetic current which has passed across the field. Third, the principle of conservation of energy is applicable to the processes just described.

Since these equations (C) and (D) contain as a special case not only that form of the law of flux which Maxwell employed in the second part of his electro-magnetic theory, but also a large variety of other forms of that law, in which the physical constants which determine the propagation of an electro-magnetic disturbance appear as functions of the periodicity of the impressed forces, and since forms of the law of flux of the same type as these latter forms were assumed hypothetically in most of the recent developments of the electro-magnetic theory of light because they lead to a tolerably satisfactory explanation of the phenomena of dispersion, absorption, rotation of the plane of polarization,—it follows that we can accept these two equations as the most general expression for the law of electro-magnetic flux.

Summary.

The main points of this essay can be summed up as follows:

Maxwell's electro-magnetic theory consists of two *distinct* parts. The essential elements of the first part are the law of induced electromotive force and the law of induced magneto-motive force. These two fundamental laws are an extension of the two experimental laws of magneto-electric and of electro-magnetic induction, which extension consists in adding to what is already contained in these experimental laws the hypotheses that the magnetic and the electric flux in dielectrics are not a mere mathematical fiction, as the older electro-magnetic theories supposed, but an actually existing state in the dielectric whose rate of variation through any imaginary surface in the dielectric is proportional to the reacting electro-motive, respectively magneto-motive force, induced around the circuit of the boundary line of this surface. The value of the reacting force is independent of the nature of the substance through which the circuit passes. Hence the physical constants of the electro-magnetic field (that is specific inductive capacity, etc.) do not appear in the first part of Maxwell's electro-magnetic theory.

The second part of this theory takes account of these constants by adding to the two fundamental laws just mentioned the ordinary form of law of flux. The first two laws are a cross-connection between the varying flux of one type and the reacting force of the other type; the law of flux, on the other hand, is a direct connection between the force and the flux of its own type. Combining the two fundamental laws with the law of flux, we obtain the fundamental differential equations of the second part of Maxwell's electro-magnetic theory. These equations are a mathematical statement of the laws of propagation of an electro-magnetic disturbance through various media, exhibiting the remarkable fact that, on the one hand, the velocity of propagation of an electro-magnetic disturbance is approximately and the wave-form of propagation is exactly the same as in the case of light; on the other hand, however, the velocity of propagation of an electro magnetic wave through a non-absorptive dielectric is independent of its periodicity, a fact which does not hold true in the case of light.* Hence although both parts of the Maxwellian theory agree well with experimental facts which were brought to light by the labors of Hertz and of other physicists who extended the Hertzian methods of investigation, yet this theory falls short of being a satisfactory theory of light, because it represents the propagation of electro-magnetic waves as inde-

* An apparent exception to this is the propagation of light through the most perfect of all dielectrics, namely, the ether in a perfect vacuum The velocity of propagation of light through this dielectric is, within the narrow limits of the visible spectrum, independent of the wave length. The question, however, whether all wave-lengths travel through pure ether with the same velocity has not yet been answered definitely. The statement, therefore, that the velocity of Hertzian waves in ether is the same as that of light is somewhat indefinite.

pendent of the periodicity of these waves, and therefore fails to account for some of the most important optical phenomena like dispersion, absorption, etc. These phenomena we know to be due to the dependence of the optical constants of a substance on the periodicity of waves; hence, if Maxwell's electro-magnetic theory is to become a satisfactory theory of light, it must be extended so as to represent the electro-magnetic constants of a substance as functions of the periodicity of the impressed electro-magnetic forces. This extension of the Maxwellian theory will affect, therefore, the law of flux only, and not the first part of this theory, since this part does not and should not contain any reference whatever to the nature of the medium of which the electro-magnetic field is composed.

This opinion is confirmed by the recent developments of the electro-magnetic theory of light, since in these the law of flux and not the two fundamental laws of Maxwell's theory appear in a modified form. Besides, it is obvious that Maxwell's form of the law of flux holds true for constant and slowly varying forces only. In every other case its application is only tentative. The second part of the Maxwellian theory should, therefore, be considered as a tentative and therefore approximate description of the laws of propagation of electro-magnetic disturbances. A more accurate description of these laws must proceed from a more general form of the law of flux, a form which will hold true for forces of all periodicities. That such a form of the law of flux actually exists is rendered highly probable by considering the most general relation between the electric and magnetic forces and their fluxes which will satisfy Maxwell's fundamental hypotheses, and also the observed fact that the electric, respectively magnetic, energy of the medium through which an integral electric, respectively magnetic, current *has passed* is a quadratic function of that integral current. This general relation is expressed by the forms (C) and (D) deduced above.

Maxwell's provisional form of the law of flux is a special case of this general relation. This general relation suggests also that many other forms of the law of flux are permissible in which those physical constants which determine the propagation of an electro-magnetic disturbance appear as functions of the periodicity of the disturbance. But these constants are not specific inductive capacity, magnetic permeabilities and resistivity of the medium.

It still remains to be shown that according to Maxwell's electro-magnetic theory a law of flux containing explicitly the periodicity of the impressed forces is not only admissible but also necessary. When that is shown, then this theory will have fulfilled one of the most essential conditions which every satisfactory theory of light must fulfill.

Effingham Park, West Islip, L. I., Aug. 20, 1895.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Conversion of the black to the red mercuric sulphide.*—In a series of careful experiments W. Spring has obtained the following values for the specific gravity and specific volume of the black mercuric sulphide precipitated, and for the red sulphide both precipitated and sublimed.

Black, precipitated.

	18°·3	23·6	35·2	56·5	77·5
Sp. grav....	7·6242	7·6047	7·5686	7·5500	7·5578
Sp. vol.....	131·160	131·496	132·124	132·452	132·313

Red, precipitated.

	21°·6	23·5	34·6	56·5	77·7
Sp. grav....	8·1289	8·1246	8·1016	8·0851	8·0871
Sp. vol.....	123·018	123·082	123·432	123·684	123·653

Red, sublimed.

	15°·8	18·0	34·6	56·6	77·5
Sp. grav....	8·1587	8·1464	8·1199	8·0906	8·0979
Sp. vol.....	122·569	122·754	123·154	123·600	123·488

The above values, treated graphically, prove that the volume varies with the temperature with both the sulphides. The expansion increases rapidly with the temperature then grows less and less, finally diminishing so as to give a maximum at about 56°. It is hence concluded that the cause of the difference in color is to be found in the constitution of the molecule and not in their orientation, that is in the crystallization. On comparing the specific gravity with the molecular weight (232), calculation shows further that the molecule of cinnabar must contain the group HgS fifteen times if the black sulphide contains it fourteen times. The following are determinations of the specific heat at different temperatures of the two sulphides, both precipitated:

	Black.	Red.	Ratio.
25° to 30°.....	0·08348	0·07487	1·115
35° to 40°.....	0·09668	0·08707	1·110
45° to 50°.....	0·11015	0·09335	1·118
55° to 60°.....	0·11034	0·09852	1·120
65° to 70°.....	0·12065	0·10737	1·123
75° to 80°.....	0·14328	0·12702	1·128

The above values of the specific heat correspond at different temperatures to those of the volumes as given above. On comparing the volumes of the black and red sulphides at the same temperature the values 0·888 and 0·932 are obtained. From these

the pressure can be calculated at which the one variety should be converted into the other. The value deduced is 34,000 atmospheres, on the supposition that the compressibility does not vary, and this not being strictly true, the required pressure in fact would be still greater or beyond the limit of experiment. The author, however, has found it possible to prepare a form of black sulphide differing less from the red in density. By subliming mercuric sulphide under ordinary conditions the red crystallized variety is formed, but if the vapors are diluted with a sufficient volume of inert gas (as CO_2, or N), a black powder is obtained containing black opaque crystals quite distinct from cinnabar and also distinct from the black variety obtained by precipitation. This variety was found to have a specific gravity of 8·0395 and a specific volume of 124·385 at 17°. For this a pressure of about 2,500 atmospheres, which it is easy to obtain, suffices to convert it into the red sulphide; the black sulphide being changed throughout its mass to the red vermilion. Finally the author finds that while the red sulphide if heated at 250° begins to turn black but assumes its red color on cooling, and while this is true up to 320°, if heated *above* 320°, it remains black permanently; this is then a critical temperature above which the red variety ceases to exist.—*Bull. Acad. Roy. Belgique*, III, xxviii, 238–257.

2. *The color, density and surface tension of hydrogen peroxide.*—Recalling the observations of Bunsen that pure water has a bluish color in a layer 2 meters in thickness and in one greater than 7·5 meters a bluish green, W. Spring states that his observations show that the color does not change with the thickness of the layer, the shade only varies. He ascribes the green tints to a yellow fluorescence produced by the play of the white light upon minute solid particles in suspension. He also notes the observations of Olzewski that liquid oxygen shows a blue color in a thickness of 30^{mm}. Further, he remarks that ozone as a gas has also a blue color in a layer of 1 meter in thickness (Hautefeuille and Chapuis), while in the liquid form it is blue and almost opaque in a layer of 2^{mm} (Olzewski). The author has now shown that hydrogen peroxide, like oxygen, ozone and water, also has a *blue color*, though hitherto it has been stated to be a colorless liquid. With great care he has prepared a considerable amount of the pure material, viz: 212 grams representing some 140^{cc} at 13°. Of this the specific gravity was found by means of a pycnometer to be 1·4996 at 1°·5, and the value of the surface tension, compared with that of water, was determined to be 0·456. The color was observed in a tube 1 meter in length; this placed vertically showed, after the bubbles of gas had disappeared, a distinct *blue* color somewhat tinged with green; the green however is regarded as non-essential. A quantitative determination of the color showed that the tint, while similar to that of water, was deeper, the relation between the two being 1 : 1·83; this was obtained by comparisons of each with layers of copper chloride of such thickness as to give the same tint. From

this fact it is argued that in hydrogen peroxide the oxygen has lost less of its properties than in water, and this, in the author's opinion, confirms the view that the constitution is expressed as a feebly united compound of the group O_2 with H_2 rather than as a union of two hydroxyl groups, HO–OH. The blue color of the sky the author regards as explained primarily by the color belonging to the oxygen, ozone, water and hydrogen peroxide present in it; it is not due, however, to transmission simply but to reflection from the earth and refraction, as a mirage of diffused light, through extensive layers of the atmosphere. The author promises to discuss this latter subject more fully later.—*Bull. Acad. Roy. Belgique*, III, xxix, 363–384.

3. *Indirect Electrolysis of a liquid.*—E. ANDREOLI has recently described a modified method for the electrical decomposition of a liquid which he calls indirect or secondary electrolysis. He employs a bath divided by plates of porous porcelain into three compartments; the end ones he fills with some conducting liquid, while the middle one contains the liquid to be decomposed; the anode and cathode are immersed in the first and last compartments, respectively. If the arrangement is simply as thus far described the passage of the electrical current results only in the decomposition of the first mentioned liquid:—thus, if it is water containing salt, chlorine is liberated at the anode and sodium hydrate formed at the cathode while the other liquid, *e. g.* gold cyanide, is unaffected. If, however, a metallic plate, or better, several plates are immersed in the liquid of the central compartment, but not connected with either pole, this liquid is now decomposed and in the case given gold is deposited on the metallic surface. Thus a lead plate opposite the diaphragm near the negative pole becomes peroxydized, while the other side is coated with gold. Metallic plates placed vertically or horizontally in the layer of liquid near the positive compartment are coated with gold. If the liquid in the end compartments is gold cyanide, no change is found in it if tested after a considerable time, while the same liquid in the central compartment has been decomposed even to the point of exhaustion. This method has also been employed to transform bisulphite of sodium into the hyposulphite; this liquid is placed in the center with two metallic plates on the positive and negative sides respectively, while any convenient conducting liquid fills the ends. The latter liquid is unaffected by the passage of the current, while the other is decomposed with the liberation of gas and a piece of linen immersed in the bath is rapidly bleached.—*Le Génie civil*, xxvii, June 29, 1895.

4. *On the Constituents of Cleveite gas.*—A paper upon this subject by C. RUNGE and F. PASCHEN is printed in the September number of the *Philosophical Magazine* (p. 297) translated from the Proceedings of the Berlin Academy (July 11).

II. Geology and Mineralogy.

1. *Glacial lakes in the Genesee valley.*—The following is an abstract of a paper on "The Glacial Genesee Lakes," read by H. L. Fairchild at the summer meeting of the Geological Society, prepared by the author. This paper covered the lacustrine history of the Genesee hydrographic area, and incidentally the whole of its Pleistocene geology. The present hydrography of the Genesee basin was shown by a handsome map. Upon this map the low points in the boundary of the basin, or the passes into other drainage systems were indicated, with their altitudes. From the head waters of the Genesee in northwestern Pennsylvania to Lake Ontario the river has a fall of two thousand feet in about one hundred and fifty miles, of which fall six hundred feet are covered by the cataracts at Portage and at Rochester. It was claimed that during the northward retreat of the ice across western New York the ice acted as a moving dam, and the ponded waters in the basin escaped by different outlets at successively lower levels. The three principal earlier outlets were into the Alleghany-Ohio drainage; the important later outlet into the Canisteo-Chemung. Counting the primary episode of local lakes in the head-water valleys, and the present Ontario phase, the author enumerated ten distinct stages in the lacustrine history of the Genesee, or nine stages of local glacial waters. The eighth stage was that of Lake Warren; the ninth that of Lake Iroquois.

The numerous evidences of water-levels throughout the basin had been studied and measured without at the first attempting to correlate them with the several outlets, but a final comparison of the height of the terraces with the height of the water-scoured cols showed a remarkable and convincing relation. It was proved that with the uncovering of each successively lower outlet the terraces, deltas and other evidences of water-levels dropped to a corresponding height, a relation entirely inconsistent with the theory of marine submergence.

Several local morainic lakes were named of which the draining streams had fallen upon rock and been compelled to make rock gorges. Two of these rock-cuts occur in the main stream, at Portageville and at Mt. Morris.

During the ice-retreat there were several local contemporary lakes in the deep side valleys before those valleys were opened into the main valley, and these local lakes had their own outlets over the divide. There were also tributary lakes, where in a few cases north-sloping valleys, outside the divide, poured their glacial waters over the divide into the Genesee basin. These and other interesting features cannot be properly located and described without the map.

It was stated that all the valleys were of preglacial origin, and that there had apparently been little reversal of drainage. The only conspicuous post-glacial work is seen in the few rock-cuttings, and in the excavation of drift from the old valleys.

2. *Supplementary Notes on the Metamorphic Series of the Shasta Region of California.* Abstract of paper read before Section E of the American Association for the Advancement of Science; by JAMES PERRIN SMITH, Stanford University, California.—The Triassic limestones of the Shasta region show the remnants of an old system of anticlines and synclines, in places very perfect. Anticlinal noses and synclinal spoons are rare phenomena in massive limestones, but here they are unusually perfect. Many fossils were collected in the, probably, Lower Permian argillites at the top of the Carboniferous limestone, among them *Fusulina* aff. *longissima*, and many brachiopoda that resemble Permian forms.

Particular attention was paid to the Upper Trias, and many species were added to the known fauna of this horizon, most of them being identical with or closely related to Alpine species. But the association of faunas was found to be new, and different from that known in other parts of the world. In the Alps and the Himalayas the *Trachyceras* fauna occurs below the zone of *Tropites subbullatus;* in the Shasta region the two faunas occur in the same beds, and even in the same hand-specimen. This is thought to indicate that either the *Trachyceras* fauna survived here longer than elsewhere, or else the *Tropites subbullatus* fauna appeared earlier in the Shasta region. The latter is thought to be the more probable, although both may be true, since the *Trachycerata* are indigenous to the Mediterranean region, while the *Tropitidæ* probably originated in the Pacific region.

The probable occurrence of the Juvavic horizon of the Trias was discussed, probably the only known occurrence of this horizon and fauna outside of the Tyrolean Alps.

3. *Ornithichnites and jaw bone from the Newark sandstone of New Jersey;* by ARTHUR M. EDWARDS, M. D. (Communicated.)—For several years I have carefully watched the quarries where the Newark (Jura-Triassic) sandstone was taken out at Newark, Arlington and at Belleville. Until now, however, I have not found large fossils except patches of the stems of ferns and Bacillariaceæ (Diatomaceæ) at Arlington. To-day at the Belleville quarry, just north of the city of Belleville, I was gratified to see some traces of larger fossils revealed in the lower levels of the quarry. These were Ornithichnites; a track of what is evidently Brontozoum with two of the joints well marked. A third is not so well marked. There are two nails of the foot evident. It is in a red shale which formed from fine-grained mud. Near by is a piece of fern, and scattered through the whitened sandstone are chrysocolla, cuprite and malachite. Last month I secured a jaw bone in excellent preservation with the teeth gone. It looks like *Dromatherium sylvestre* of Emmons. There are also slabs with markings on them which I cannot identify.

Newark, N. J., Sept. 11, 1895.

4. *Missouri Geological Survey—Lead and Zinc Deposits*, by ARTHUR WINSLOW, assisted by James D. Robertson, vols. vi and vii, pp. i–xxi, 1–763, plates i–xli, figures 1–268. Jefferson City, Mo., 1894.—The importance of the lead and zinc industry in Missouri is full justification for the preparation of this exhaustive treatise on lead and zinc deposits, by the geological survey of that state. The construction of the report follows the general lines of the admirable manganese report of Dr. Penrose, published by the Arkansas survey. The first part (pp. 1–507) is a summary account of the history, compounds, modes of occurrence and distribution of lead and zinc throughout the world, the final chapter of which, on the industries and statistics of lead and zinc, was written by Mr. Robertson. Although this part is chiefly a compilation, with its accompanying bibliography and frequent reference to sources, it will be of much value to the student as well as to the investor. The remainder of the report is devoted to an account of the history of mining in Missouri, the physiography and geology of the mines, and a detailed description of the several ore deposits and mines distributed throughout the state.

The investigations, which led to the writing of the report, were begun in 1889 in coöperation with the United States geological survey, whose representative, Dr. W. P. Jenney, collected a large body of facts illustrating the subject. Mr. Robertson of the state survey coöperated with Dr. Jenney in these investigations and was a co-worker with Mr. Winslow in the preparation of this final report.

Although communicated to the board of managers by Mr. Keyes, the report was planned and executed entirely by the late State Geologist, Mr. Winslow, who is to be congratulated upon the production of a work which brings together, in such orderly and satisfactory form, the knowledge up to date regarding the distribution and mode of occurrence of these mineral products.

The author's theory of the origin of the metalliferous minerals in the ore bodies is, briefly, that they were introduced into the cavities where they have been mined, "in solution," and that the source of these solutions was "original diffusion through the country rocks, and subsequent concentration through surface decomposition of the latter, supplemented by percolating waters."

H. S. W.

5. *Geological Survey of Canada.*—The Annual Report for 1892–93 has appeared. It contains, besides the usual summary reports of work done in the years 1892 and in 1893, two strictly geological reports, viz: "Preliminary Report on the Geology of a portion of Central Ontario," by FRANK D. ADAMS, and "Prelim. Report on Geological investigation in Southwestern Nova Scotia," by L. W. BAILEY. There are also "Chemical contributions" by G. CH. HOFFMANN and his assistants, and "Mineral Statistics and Mines" for 1892 by E. D. INGALL and his assistants. (Geol. Surv. Canada, A. R. Selwyn Direct., Ann. Rept. (new series), vol. vi, Repts. A (1892), A (1893), J, Q, R, S, 660 pages, Ottawa, 1895.)

6. *The Geological Society of America.*—The Geological Society held its seventh summer meeting in Springfield, Mass., August 27th and 28th, N. S. Shaler presiding. The following is a list of the papers presented:

GEO. M. DAWSON and R. G. MCCONNELL: Glacial deposits of Southwestern Alberta, in the vicinity of the Rocky Mountains.

C. H. HITCHCOCK: The Champlain glacial epoch.

WARREN UPHAM: Drumlins and marginal moraines of ice-sheets.

H. L. FAIRCHILD: The glacial Genesee Lakes.

B. K. EMERSON: The geology of old Hampshire county in Massachusetts.

N. H. DARTON: Notes on relations of lower members of coastal plain series in South Carolina. Resume of general stratigraphic relations in the Atlantic coastal plain from New Jersey to South Carolina.

ARTHUR HOLLICK: Cretecceous plants from Martha's Vineyard. Results obtained from an examination of the material collected by David White in 1889.

R. T. JACKSON and T. A. JAGGAR: Arrangement and development of plates in the Melonitidæ.

GEORGE P. MERRILL: On asbestos and asbestiform minerals.

WILLIAM H. HOBBS: Pre-Cambrian volcanoes in Southern Wisconsin.

A. CAPEN GILL: A geological sketch of the Sierra Tlayacac, in the State of Morelos, Mex.

C. H. GORDON: Syenite-gneiss (Leopard Rock) from the Apatite region of Ottawa county, Canada.

J. F. KEMP: The titaniferous iron ores of the Adirondacks.

J. C. BRANNER: The decomposition of rocks in Brazil.

W. M. DAVIS: The bearing of physiography on Uniformitarianism.

C. R. VAN HISE: Analysis of folds.

N. S. SHALER: On the effects of the expulsion of gases from the interior of the earth.

7. *La Géologie Comparée, par Stanislas Meunier*, pp. 1–296, figures 1–35, Paris, 1895 (Bibl. Scientifique Internationale).—M. STANISLAS MEUNIER of the Natural History Museum of Paris, author of numerous papers on meteorites, has brought together in an attractive form, with typical French vivacity, a large body of facts illustrating the geological relations of the other planets of the solar system to the earth. The work is illustrated by 35 figures in the text, showing the forms of surface configuration of the planets and of structure of meteorites like those known on the earth. The author describes a number of remarkable similitudes between celestial and terrestrial objects, which are certainly interesting, though the reader may hesitate to adopt the author's conclusions.

8. *Die Eruptivgesteine des Kristianiagebietes: I Die Gesteine der Grorudit-Tinguait Serie;* by W. C. BRÖGGER (Videnskab. Skrift 1 math. natur. Klasse, 1894, No. 4. Kristiania, 8°, pp. 206, 4 plates, etc.)—In his great work on the syenite-pegmatite dikes of southern Norway, Professor Brögger promised that this should soon be followed by a monograph on the eruptive rocks of the same district. The appearance of this volume has been eagerly awaited by all workers in this field of science. In his preface to the present work, the author states that he has been unable to carry out this plan and he now proposes to cover the same ground by a series of monographs on special subjects of which this, treating of a closely-related series of rock types, is the first.

It is to be followed by one dealing with the well known "rhombic porphyries."

The rocks now under discussion occur in dikes and are fine-grained and porphyritic. They consist essentially of alkali-feldspars and ægirite; where the silica percentage is high, quartz is also developed (grorudite); with falling silica it disappears (sölvsbergite) and below 60 per cent nephelite comes in as an important constituent (tinguaite). A fourth member of the series would be a rock with silica below 50 per cent and with nephelite preponderating over feldspar. This type the author recognizes in a rock described by Kemp* from Beemersville, N. J. and proposes for it the name of *sussexite*. This name, however, is clearly objectionable, if indeed it be not entirely ruled out by the fact that it has been applied since 1868 to a well-defined mineral species occurring at Franklin Furnace, N. J.

These rock types are described as to their occurrence in the field and mapped. Their petrology is discussed in detail and is accompanied by many analyses, plates, drawings and tables of mineral contents. Incidentally the author takes occasion to discuss and classify the alkali-iron hornblendes, introducing a new member to which the name of *kataforite* is given. His classification is as follows:

Barkevikite	angle $c \wedge c$ small 12°–14°	TiO_2 rich	ruling *brown* absorption colors	pleochroism $c > b > a$
Kataforite	angle $c \wedge c$ large 30°–60°	TiO_2 poor	ruling red absorptions	$b > c > a$
Arfvedsonite	angle $c \wedge c$ very large	TiO_2 free	ruling greenish	
Riebeckite?	75–86		blue colors	$a > b > c$.

A large portion of the book is devoted to theoretical petrology, and it is this that will be read with the greatest interest. Many new and important questions are brought up and discussed and much light is thrown upon old ones. In the brief limits of this notice it is impossible to do more than merely mention this fact, but it may be safely said that the importance of the present work in its bearing on general petrology can hardly be overestimated. L. V. P.

9. *Directions for collecting rock specimens.*—A useful series of papers, giving specific directions for collecting specimens in the field and preparing them for safe shipment, has been prepared by the Smithsonian Institution. Sufficient illustrations are given to guide the untrained in the preparation of tools and in methods of manipulation. The articles are entitled as follows: "Directions for collecting rocks and for the preparation of thin sections," by GEORGE P. MERRILL, 15 pp.; "Directions for collecting and preparing fossils," by CHARLES SCHUCHERT, 31 pp.; "Directions for collecting specimens and information illustrating the aboriginal uses of plants," by FREDERICK V. COVILLE, 8 pp., and "Directions for collecting minerals," by WIRT TASSIN, 6 pp. (Bull. U. S. Nat. Mus., No. 39, Washington, 1895.)

* Trans. N. Y. Acad. Sci., vol. ii, p. 60, 1892.

10. *A preliminary Report on the Marbles of Georgia;* by S. W. McCallie. Bulletin No. 1, Geol. Survey of Georgia, W. S. Yeates, State Geologist.—This bulletin presents an account of the marbles of Georgia and the general condition of this industry at the present time. It is interesting to note that this State, in which the production for 1893 was valued at $261,666, stands second in the country in its production of marble. Vermont comes first with an output for the same year valued at $1,621,000 and New York third with one of $206,926; while for Tennessee and Maryland the corresponding values were $150,000 and $130,000 respectively.

11. *On some Swedish minerals;* by Hj. Sjögren.—A recent number of the *Bulletin of the Geological Institution of the University of Upsala* (vol. ii, part I, No. 3) contains an important article by Sjögren on some Swedish minerals (pp. 39 to 108). The subject of the chemical composition of the minerals of the Humite-Chondrodite group is reviewed with new analyses by Mauzelius on carefully selected material. The formulas derived are as follows:

Chondrodite	$Mg_3[Mg(F.OH)]_2(SiO_4)_2$
Humite	$Mg_5[Mg(F.OH)]_2(SiO_4)_3$
Clinohumite	$Mg_7[Mg(F.OH)]_2(SiO_4)_4$

These formulas agree perfectly with those deduced independently and a little earlier by Penfield and Howe (this Journal, xlvii, 188, March, 1894).

In continuance of the same subject a description is given of Prolectite, a new mineral of the above group. This, owing to lack of material, has been only partly investigated thus far. It crystallizes in the orthorhombic system and its relations to the other species is as follows:

	Ratio of vertical axes.
Prolectite	3
Chondrodite	5
Humite	7
Clinohumite	9

With the three long known species the ratio above given is also—as first shown by Penfield and Howe—that of the magnesium atoms present (see formulas above). This fact led the authors named to suggest the probable discovery of another member of the group with the formula $Mg[Mg(F.OH)]_2SiO_4$, and although prolectite has not yet been analyzed it is urged by Sjögren that its composition will probably be found to conform to this. The name (from *προλεγειν* to *foretell*) alludes to the fact that its existence was thus predicted.

A description is also given of Retzian, a new arsenate from the Mossgrufva, Nordmark. It occurs in small orthorhombic crystals imbedded in a mixture of dolomite and braunite. They have a chestnut-brown or chocolate-brown color; hardness about

4; specific gravity 4·15. In form it is closely related to flinkite, but its chemical composition is not entirely settled, the following partial analysis by Mauzelius having been made on a very minute quantity (0·08 gr.):

As_2O_5	MnO	FeO	PbO	CaO	MgO	SiO_2	H_2O	X	
24·4	30·2	1·7	0·2	19·2	2·7	0·5	8·4	14·6	=101·9

X including insoluble 4·3 and not identified 10·3.

Another point of interest is the description of URBANITE (see this Journal, July, p. 76), which is shown to belong to the pyroxene group. An analysis by Mauzelius gave:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	ign.	
G.=3·52	51·61	0·74	27·24	0·54	1·73	4·90	2·75	10·59	0·36	0·90	=101·36

Descriptions are also given of a soda-richterite, a soda-berzelite, of the partially known mineral caryinite, of crystallized safflorite, of magnetite in cubic crystals, etc.

12. *Ueber gewundene Bergkrystalle;* von G. TSCHERMAK. Vienna, 1894 (Denkschriften der K. Akad. Wissenschaften, vol. lxi).—The remarkable crystals of quartz, not uncommon in Switzerland but known also from other localities, having curved faces and more or less twisted axial systems, have been minutely studied by Tschermak. He, while confirming the early observations of Weiss as to the regularity of these growths, has gone further and offered an explanation for them. This is based on the assumption of the simultaneous existence of three different methods of twinning. The first, which the majority of the specimens show, is the common law characteristic of many quartz crystals in which a plane of the hexagonal prism is the twinning plane. In the second law, the twinning plane is inclined to the vertical axis in the direction of the fundamental rhombohedron and very nearly perpendicular to it; in the third, the twinning plane is a face of a twelve-sided prism varying but little in position (only 1′ 40″) from that of the second prism. Several types of forms are shown to exist which are explained according as to whether two or three of these methods of twinnings coexist, and also determined by the method of their combination. The second and third twinning planes mentioned are properly vicinal planes, and hence the corresponding twins may be called *vicinal twins.* At the same time the suggestion is made that these vicinal twinning planes become fundamental planes with simple indices if it is assumed that the crystallization of quartz is not hexagonal-trapezohedral (tetartohedral), but triclinic-hemihedral. The plates accompanying the text give beautiful representations of some of the remarkable forms described, in which not only the deep smoky-brown color, but even the luster of the surface are faithfully reproduced.

III. Miscellaneous Scientific Intelligence.

1. *American Association for the Advancement of Science.*— The forty-fourth meeting of the American Association was held at Springfield, Mass., from August 28 to Sept. 4. The President of the meeting was Prof. Edward W. Morley of Cleveland. In the absence of the retiring President, Dr. D. G. Brinton, his address on the Aims of Anthropology was read by the General Secretary. Addresses were also delivered before the several sections, by their respective Vice-Presidents. The attendance at the meeting was not large, under four hundred, but the papers presented were numerous, as shown in the list given below, and the general success of the meeting was regarded as satisfactory; this was largely due to the excellent arrangements made by the local committee.

The next meeting was appointed for August, 1896, at Buffalo, N. Y., and Professor E. D. Cope was chosen President. The Vice-Presidents elected for the several sections are as follows: *Section A*, Wm. E. Story of Worcester, Mass.; *Section B*, Carl Leo Mees of Terre Haute, Ind.; *Section C*, W. A. Noyes of Terre Haute, Ind.; *Section D*, F. O. Marvin of Lawrence, Kansas; *Section E*, B. K. Emerson of Amherst, Mass.; *Section F*, Theodore N. Gill of Washington; *Section G*, N. L. Britton of New York City; *Section H*, Alice C. Fletcher of Washington; *Section I*, W. R. Lazenby of Columbus, O.

The following is a list of the papers accepted for reading before the several sections.

Section A. *Mathematics and Astronomy.*

J. B. Shaw: Development of some useful quaternion expressions, with applications to geometry of three and four dimensions.

C. L. Doolittle: The constant of aberration.

S. C. Chandler: On the constant of nutation.

A. N. Skinner: Progress of the zone work at the Naval Observatory, Washington, D. C.

L. A. Bauer: On the distribution and the secular variation of terrestrial magnetism.

M. A. Veeder: Sunspots and magnetic storms.

Edwin B. Frost: The spectrum of β Lyræ.

Artemas Martin: Notes on square numbers whose sum is either a square or the sum of other squares.

Albert S. Flint: Some results for stellar parallax from meridian transit observations at the Washburn Observatory.

Mary Proctor: Making astronomy popular.

Edgar Frisby: A convenient formula for computing times of moon rising. On a slide scale for computing precession.

Samuel W. Balch: Chronology and ancient eclipses.

H. M. Parkhurst: Period of R Comæ.

Section B. *Physics.*

M. I. Pupin: Flow of alternating current in an electrical cable. The most general relation between electric and magnetic force and their displacements.

J. H. Pillsbury: The significance of color terms. On standard colors. The analysis of floral colors.

Frank P. Whitman: On the comparison in brightness of differently colored lights and the "flicker" photometer.

E. R. VON NARDROFF: A new apparatus for studying color phenomena.

F. S. MUCKEY and WILLIAM HALLOCK: Voice production, with photographs of the vocal cords in action. Voice analysis, with photographic record.

W. LECONTE STEVENS: Note on the limits of range of the human voice.

J. F. MOHLER and W. J. HUMPHREYS: Observations on the relations of certain properties of line spectra to the physical conditions under which they are produced.

F. E. IVES: The reproduction of colors by photography.

WILLIAM HALLOCK: Electrolytic reproduction of resonators. A photographic method of comparing the pitch of tuning forks. Illustration of gems, seals, etc. Color definitions for the Standard dictionary.

WM. A. ROGERS: An examination of the statement of Maxwell that all heat is of the same kind. A new determination of the relative lengths of the yard and meter. The effect of age upon the molecular structure of bronze, glass and steel.

E. W. MORLEY and WM. A. ROGERS: Expansion of Jessop's steel, measured by interferential method.

JOHN D. PARKER: California electrical storms.

L. A. BAUER: A new formulation of the second law of thermodynamics.

FREDERICK BEDELL: The method of reciprocal points in the graphical treatment of alternating currents.

H. D. CARHART: An experimental investigation of the rotatory field.

C. D. CHILD: Phenomena with electric waves analogous to those of light with a diffraction grating.

WILLIS L. MOORE: Relations of the Weather Bureau to the science and industry of the country.

FRANK H. BIGELOW: Solar magnetic radiation and weather forecasts.

CLEVELAND ABBE: Clouds and their nomenclature.

ALFRED J. HENRY: Cloud photography.

SECTION C. *Chemistry.*

W. P. MASON: Foreign laboratory notes.

ELLEN H. RICHARDS and J. W. ELLMS: The coloring matter of natural waters; its source, composition and quantitative measurement.

H. N. STOKES: Helium and argon.

F. P. VENABLE: Recent views on the periodic system.

C. H. HERTY: Double salts and allied compounds.

E. W. MORLEY: On the volumetric composition of water.

W. A. NOYES: Camphoric acid. Journal reviews.

ALEX. SMITH: Constitution of the 1 : 4 dikestones.

P. C. FREER: The constitution of tetrinic acid. The teaching of organic preparations: the time, scope, methods and previous preparations. On the sulphides of arsenic formed in analytical work.

A. B. PRESCOTT: Periodides. Periodides of pyridine. A few pyridine alkyl normal iodides. Some inquiries respecting inherent limitations in the accuracy of analytical work in general.

R. F. FLINTERMAN and A. B. PRESCOTT: Dipyridine trimethylene dibromide.

C. L. JACKSON: Some new color reactions. A second modification of picrylmalonic ester. Instruction in general chemistry.

C. B. DUDLEY: Remarks on international standards of analysis of steel.

A. A. BLAIR and J. E. WHITFIELD: Ammonium phospho-molybdate and the reducing action of zinc in the reductor.

E. D. CAMPBELL: Provisional schedule of admissible limits of accuracy in certain metallurgical analyses.

F. P. DEWEY: Accuracy in metallurgical analysis.

T. H. NORTON: On the use of thioacetic acid as a laboratory reagent. The phosphorus contained in phospho-cereal. Discussion on important phases of didactic chemistry. Laboratory construction and equipment.

R. B. WARDER: The major premise in physical chemistry.

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SECTION D. *Mechanical Science and Engineering.*

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MANSFIELD MERRIMAN: On partially continuous drawbridge trusses, with a method of deducing formulas for the reactions.

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SECTION E. *Geology and Geography.*

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SECTION F. *Zoology.*

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SECTION G. *Botany.*

FREDERICK V. COVILLE: Poisoning by broad-leaved laurel. Botany of Yakutat Bay, Alaska.

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SECTION H. *Anthropology.*

F. H. CUSHING: The dynasty of the arrow.

STEWART CULIN: The origin of playing cards. The origin of money in China. Mustache sticks of the Ainus.

JOHN G BOURKE: Some Arabic survivals in the language and folk-usage of the Rio Grande valley.

*This paper and those immediately following were read before the Botanical Club.

ALICE C. FLETCHER: The sacred pole of the Omaha tribe. Indian songs and music.

W. W. TOOKER: The mystery of the name Pamunkey. The Algonquian appellatives of the Siouan tribes of Virginia.

WASHINGTON MATTHEWS: A vigil of the gods.

W. Z. RIPLEY: A study in anthropo-geography as a branch of sociological investigation.

STANSBURY HAGER: A melange of Micmac notes.

J. W. B. HEWITT: Grammatic form and the verb concept in Iroquoian speech. The cosmogonic gods of the Iroquois.

ARTHUR MACDONALD: Anthropometrical, psycho-neural and hypnotic measurements.

J. D. WRIGHT: The education of blind-deaf mutes.

L. O. TALBOT: A study in child life.

FRANZ BOAS: The Indians of Southern California.

ALEX. F. CHAMBERLAIN: Word formation in the Kootenay language. Kootenay Indian personal names.

R. G. HALIBURTON: The year of the Pleiades of prehistoric star-lore. The influence of prehistoric pigmy races on early calendars and cults, with notes on dwarf survivals.

W. M. BEAUCHAMP: An Iroquois condolence. Old Mohawk words.

J. MCKEEN CATTELL: Mental measurements in anthropology.

F. W. PUTNAM and C. C. WILLOUGHBY: Some symbolic carvings from the ancient mounds of Ohio.

F. G. WRIGHT: Account of the discovery of a chipped chert implement in undisturbed glacial gravel near Steubenville, Ohio.

GEORGE LEITH: Notes on the bushmen of Transvaal.

STEPHEN D. PEET: Village life among the cliff dwellers. The Palæolithic cult, its characteristic variations and tokens. The different races described by early discoverers and explorers.

HARLAN I. SMITH: An Ojibwa transformation tale.

F. H. CUSHING: The spider goddess and the demon snare.

SECTION I. *Economic Science and Statistics.*

J. W. SYLVESTER: A system of co-metallism.

HENRY FARQUHAR: An international coinage.

T. C. MENDENHALL: The law of chance, illustrated in railway accidents.

W. R. LAZENBY: Manual training in horticulture for our country schools.

J. L. COWLES: Equality of opportunity; how can we secure it?

W. L. O'NEILL: On suicide.

E. L. CORTHELL: Growth of great cities.

MARY J. EASTMAN: A cottage settlement in Spain.

2. *Iowa Academy of Sciences.*—The exceptional privilege is enjoyed by the Iowa Academy of Science of having its Proceedings published by the State. Volume ii of the Proceedings for 1894 has appeared, making a volume of 225 pages, containing a number of valuable papers on geology and other branches of science. Several papers on glacial and preglacial geology, on stratigraphical problems, on paleontology—one on "Synopsis of American Paleozoic Echinoids" by C. R. Keyes, and others are of importance to those interested in the geology of the Mississippi Valley.

OBITUARY.

PROFESSOR C. V. RILEY, the able and well known Entomologist of the Agricultural Department, died suddenly at Washington, D. C., on the fourteenth of September.

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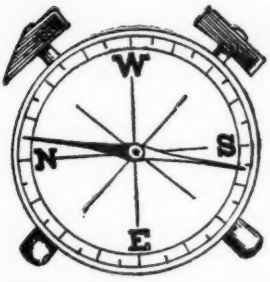

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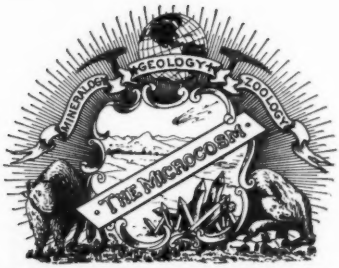

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J. WILEY & SONS, New York.—**System of Mineralogy** of J. D. DANA. 6th edit. by EDWARD S. DANA. lxiii, 1134 pp. large 8vo., 1892. $12.50. 5th edit., 1868, with three appendices, 1872, 1875, 1882. $5.00.—**Manual of Mineralogy & Lithology,** by J. D. DANA. 4th edition. 517 pp. 12mo., 1887, $2.00.—**Text-book of Mineralogy,** by E. S. DANA. Revised edition. 512 pp. 8vo., 1883, $3.50.—**Minerals and How to study them;** a book for beginners in Mineralogy, by E. S. DANA. 380 pp. 12mo., 1895, $1.50.—**Text-book of Elementary Mechanics,** by E. S. DANA. 300 pp. with numerous cuts, 12mo., 1881.

DODD & MEAD, New York.—**Corals and Coral Islands,** by J. D. DANA. 440 pp. 8vo. 3d ed., 1890.—**Characteristics of Volcanoes,** with contributions of facts and principles from the Hawaiian Islands, by J. D. DANA. 399 pp. 8vo. With illustrations, maps, etc. 1890.

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CONTENTS.

Page

ART. XXIX.—Recent Progress in Optics; by W. LECONTE STEVENS 277

XXX.—Quantitative Determination of Perchlorates; by D. A. KREIDER 287

XXXI.—Occurrence of Copper in Western Idaho; by R. L. PACKARD 298

XXXII.—Demonstration of Caustics; by R. W. WOOD ... 301

XXXIII.—Spectrum of Helium; by W. CROOKES 302

XXXIV.—Igneous Rocks of the Sweet Grass Hills, Montana; by W. H. WEED and L. V. PIRSSON 309

XXXV.—Distribution and Secular Variation of Terrestrial Magnetism, No. III; by L. A. BAUER 314

XXXVI.—Studies in the Electro-magnetic Theory.—I. The law of electro-magnetic flux; by M. I. PUPIN 326

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Conversion of the black to the red mercuric-sulphide, W. SPRING, 342.—Color, density and surface tension of hydrogen peroxide, W. SPRING, 343.—Indirect Electrolysis of a liquid, E. ANDREOLI: Constituents of Cleveite gas, C. RUNGE and F. PASCHEN, 344.

Geology and Mineralogy—Glacial lakes in the Genesee valley, H. L. FAIRCHILD, 345.—Supplementary Notes on the Metamorphic Series of the Shasta Region of California, J. P. SMITH: Ornithichnites and jaw bone from the Newark sandstone of New Jersey, A. M. EDWARDS, 346.—Missouri Geological Survey—Lead and Zinc Deposits, A. WINSLOW: Geological Survey of Canada, 347.—Geological Society of America: La Géologie comparée, S. MEUNIER: Eruptiv gesteine des Kristianiagebietes: I Die Gesteine der Grorudit-Tinguait Serie, W. C. BRÖGGER, 348.—Directions for collecting rock specimens, 349.—Preliminary Report on the Marbles of Georgia, S. W. MCCALLIE: Some Swedish minerals, HJ. SJÖGREN, 350.—Ueber gewundene Bergkrystalle, G. TSCHERMAK, 351.

Miscellaneous Scientific Intelligence—American Association for the Advancement of Science, 352.—Iowa Academy of Sciences, 356.

OBITUARY—Professor C. V. RILEY, 356.